STUDIEVERENIGING KOers
CONSTRUCTIEF ONTWERPEN

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Offshore & Foundations

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Dear reader,

"A structural engineer analyzes and designs the gravity support and lateral force resistance of buildings, bridges, and other structures"
"Structural engineers are creative innovators, they use math and science to design structures, solve problems, and shape the world around them."
"Structural engineers design structures to withstand stresses and pressures imposed through environmental conditions and human use."

I found these quotes on Google using the search terms: 'definition of a structural engineer'. As structural engineering students, we generally think of designing buildings and structures like bridges and tunnels, but there are some specializations and other fields in structural engineering that are interesting as well and deserve some extra attention. Therefore, as editorial board, we present you in this edition of the KOersief two specific areas of structural engineering: offshore and foundations.

This edition consists of articles about different types of foundations on land and in water. We also present you articles about different offshore projects and we talked with specialists on floating and offshore structures.

Besides these articles, you can enjoy our usual features: a journal about the world-record-breaking bridge made out of beer crates; a graduation project about the behavior of timber in compression perpendicular to the grain; a travel blog from Australia; a journal about the ENCI-Multiple Day Excursion; the KOers Education update, and we will finish with the usual column by our very own Hans Lamers. We hope you will enjoy reading this 99th edition.

On behalf of the editorial board,

Thomas van Vooren
Editor-in-chief KOersief 99

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Chairman's note

Dear KOers members and relations,

The academic year has almost come to an end. In the first half year of 2016, KOers organized many large activities. In February, the ENCI-Multiple Day Excursion took place. Sixteen students visited Munich and Stuttgart. During the Dream & Dare Festival in April, in honor of the 60th anniversary of the TU/e, the world record attempt of the Beer Crate Bridge took place. And with success! The Beer Crate Bridge, for the first time actually built over water, had a span of 26.69 meters and crushed the old world record of 22.15 meters. This edition of the KOersief contains daily reports about both the ENCI-Multiple Day Excursion and the Beer Crate Bridge.

In the first two weeks of May, nineteen students joined the Foreign Study Trip to Singapore for ten days. In the last weekend of May, KOers participated in the Concrete Canoe Race in Arnhem. While writing this note, these activities have not taken place yet. The next edition of the KOersief will contain reports about these activities.

In addition to these activities, excursions, and lunch lectures were organized. A group of students went on excursion to the Student Hotel and Kennedy Business Center in Eindhoven and to the ENCI cement factory in Maastricht.

One of the goals of the 46th board was to bring students and companies in the field of Structural Design closer to earch other by organizing lunch lectures and excursions. On top

of that, the Continu Career Event was organized. This event started with a short presentation followed by a course, in which students got the chance to learn about networking with companies. In the upcoming period, fewer activities will be organized due to the lecture free months. In September, a new board will be installed.

The theme of the 99th edition of KOersief is 'Offshore & Foundations'. I hope you will enjoy reading this edition that treats an interesting and educational subject of structural design!

Yours sincerely,
On behalf of the 46th board of KOers,

Gosse Slager
Chairman of the 46th board of KOers

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Agenda

ENCI-MDE Munich & Stuttgart *February 18th-21th*

Excursion Kennedy Business Center and the Student Hotel *March 3rd*

General Members Meeting

September TU/e, Eindhoven

The reign of the 46th board will come to an end and the 47th 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!

Lunch Lecture

September Trappenzaal, TU/e, Eindhoven

The 8th lunch lecture of the 46th board will be organized in September. The date, time, and theme of the lunch lecture is to be announced.

KOers Introduction Day

September TU/e, Eindhoven

Every year, new members of KOers are welcomed at the KOers Introduction Day. This day starts off with a drink in the afternoon, followed by an activity. Last year, the 46th board organized a KOers Pub Quiz and the year before, a bowling night was organized.

KOersief 100 release

TBA TU/e, Eindhoven

The release of the 100th KOersief will be special, so keep an eye out for the announcement!

Lunch Lecture Movares about bio-based materials *March 31th*

Huizen- & Disputenrace *May 18th*

Beer Crate Bridge 2016 *April 23th*

Sjoelborrel *May 23th*

The structural design of pipelaying and heavy-lifting vessels

Structural engineering in the offshore industry

Interview with: Jasper Slob
Structural Engineer at Allseas

By: Tom Godthelp & Angelique van de Schraaf
Editors KOersief

There are similarities between offshore structural design and the structural design of buildings. This was the reason for KOersief to contact the Dutch offshore company Allseas. In this interview, you can read that offshore engineering can provide interesting opportunities for Structural Design students at the TU/e. Tom and Angelique spoke with Jasper Slob, structural engineer at Allseas in Delft.

What kind of company is Allseas?
Allseas is a world leading contractor in offshore pipeline installation, heavy lift, and subsea construction. For over 30 years, the company has been developing cutting-edge technology and pushing the boundaries to deliver state-of-the-art solutions to meet the market's ever-changing needs. Worldwide Allseas employs over 3,000 people and operates a versatile fleet of specialised heavy-lift, pipelay and support vessels, designed and developed entirely in-house.

From our engineering and project management hub in Delft, we design and develop new products and processes that enable our vessels to execute more challenging projects safer, faster and more efficiently. Our latest vessel, the 382 meters long, 124 meters wide platform installation/decommissioning and pipelay vessel Pioneering Spirit, has been designed and engineered at our Delft office. I also worked on this project. This multi-billion dollar vessel is the biggest construction vessel in the world, designed for single-lift installation and removal of large offshore oil and gas platforms and the installation of record-weight subsea pipelines.

Across its offices in Delft, Eindhoven, and Enschede, Allseas employs about 850 people, among them some 50 structural engineers. We are ultimately responsible for the structural engineering design, review, and construction of a project.

Can you describe your function?
At the office in Delft my function is structural engineer. In my position, I make structural calculations of certain parts of the ship. For instance, a modification in the ship to add an oil reservoir. For this job I maintain close contact with the drawing department that makes the first the design, which I then analyse. Changes are then made to the design until a final design is created. The outcome of this design with reaction forces will have an influence on the rest of the ship. These results are passed on to other engineers and to third parties involved. You can imagine that many engineers and third parties are involved when designing, for instance, a ship like the Pioneering Spirit. When I make changes to the ship, engineering colleagues from other departments need to check the overall consequence of the change. Together, we then find the most suitable solution to ensure, for example, the overall stability of the ship.

How did you end up at Allseas?
I became interested in offshore structures due to my brother's study. He studied Marine Technology and Offshore Engineering in Delft, and through him I heard about Allseas. He graduated in offshore structures and had very nice stories about the business, for instance, the huge scale of some offshore equipment. This really appealed to me and made me decide to visit the Allseas presentation at a technical

company day. After my graduation, I applied for the function of structural engineer at Allseas in February 2014 and started working for the company a month later.

I have a bachelor in Aerospace Engineering and a master in Aerospace Structures and Materials. During my study, I followed courses like structural mechanics, materials, and dynamics. So the switch to offshore design was feasible for me. If I see the real sizes of parts on which I have worked, I am always impressed. When you are designing and developing parts with a computer it is difficult to imagine the real scale, but when you see a structure before you that is 65 meters tall and five meters wide, you are stunned. I really like this part of my job and therefore my choice for the offshore industry was the right decision.

Structural design in offshore

Can you describe the design process of a ship and is this comparable with the design process of a building?

The design process for a ship starts with an initial idea. The original concept for Pioneering Spirit, for example, was born in 1985 and engineers have spent the last 30 years modifying and perfecting the design. The Pioneering Spirit is the first Allseas vessel to be designed from scratch. The other vessels were bought and converted for a specific function. In that case, specific technical drawings are often only available in 2D or in a bad shape. Therefore, our engineers have to go to the ship to take specific measurements and photos to be able to make 3D drawings. With this information, the (customizing) engineering can take place and the design process can start. During this design process, various parties are involved, for instance, the engine manufacturer or the piping engineers. This multidisciplinary design process is, in a way, comparable to the building industry, where various parties are involved as well. It comes down to the fact that neither the structural offshore engineer, nor the architectural structural engineer can make big design decisions without a multidisciplinary consult.

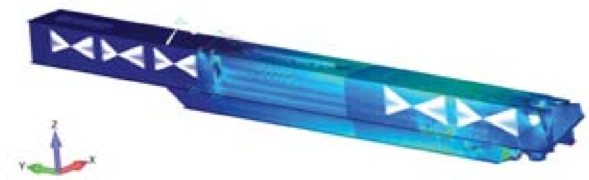

Figure 1: FEM simulation of the Pioneering Spirit's lift system

Figure 2: Lift system in assembly

Does standardization determine a great part of your work?

If the ship can leave the dry-dock faster when applying standardized solutions, the choice is easily made and we decide to apply standardized solutions. Besides, the maintenance intensity is an important issue during the design process nowadays. Therefore, standardized parts are often the best choice. This as a result of the fact that maintenance costs mostly determine the life cycle and application costs of a ship. The majority of the ships are designed with standardized items. However, when adding, for instance, a pipe laying system or a platform lifting system, the standardized elements do not comply and special engineering is required.

How do you calculate the different ship parts?

First, I calculate the rough dimensions by means of the standard mechanical formulas. I use these simple calculations every day. Afterwards, I check the force distribution with finite element (FE) software. After the force distribution in the model is clear, I for instance check some steel joints, using Eurocode 3. In the FE model, I use a stepwise approach to keep the model clear and understandable. The responsible engineers make a complete FE model of the ship to check the effect of my resultant forces on the rest of the ship. We do not have a software interaction between the FE model and the technical drawings of the ship. Modifications we would like to apply have to be passed on manually to the technical draftsman. But that is not all. The biggest challenge for me is to imagine the scale of forces and the scale of elements in reality. All the equipment is really huge and it is hard to visualize the force distribution when comparing it to the human scale. This type of visualization is very important in my job as structural engineer.

In the shipbuilding industry, steel is the most commonly used material, so I carry out almost all my calculations with this type of material. Aluminium and stainless steel are also used, but in much smaller quantities.

Which design codes do you use?

We use several different design codes. Lloyd's Register Code for lifting appliances and Mobile Offshore Units are used as major design code. The Eurocode 3 (steel structures) is used in conjunction with the above. This code is complemented with several additional documents, such as, documents of the DNV (Det Norske Veritas) and Allseas in-house specifications.

Allseas are classified under Lloyd's Register. This institution is comparable with the construction supervision of buildings by the Dutch municipalities. Lloyd's check is necessary in order to insure the ship. In addition, this type of check is necessary to sail through and work in some territorial waters.

Jasper Slob (29, The Hague) obtained his high school degree in Zürich, Switzerland. After his Bachelor in Aerospace Engineering at the Technical University of Delft, he completed his Master Aerospace Engineering with the specialisation: Design and Production of Composite Structures. He did a master internship at Lockheed Martin Aeronautics in Fort Worth, Texas, USA. Since March 2014, he has worked as a structural engineer at the offshore company Allseas within the department of Innovations.

Which steel qualities are common in the offshore?
The following steel qualities are common:

- S355, is the standard steel quality we use for all our ships;
- S460, is increasingly used in the ship building industry;
- S690, is used for special equipment. A special design is needed when applying this type of high grade steel because of the tough weldability.

Which software do you use?
At Allseas we use the following design software:

- FE software: FEMAP (Nastran), Ansys, Abaqus, Marc;
- Calculations: Mathcad;
- Drawings: Inventor, AutoCad.

Figure 3: Lift system installed on the Pioneering Spirit

A Structural Design student in offshore engineering
Do you think a Structural Design student can become structural engineer at Allseas?
Yes, I think that is possible. If you followed structural mechanics courses and have knowledge about FE software and steel structures, it is possible. For some calculations, knowledge about dynamics is required, but everything can be learned during projects if you understand the basics of structural engineering. When you do not have enough knowledge about, for instance, FE software, it is possible to attend training courses at Allseas. In addition, you can learn a lot from colleagues.

What are the career opportunities for structural engineers at Allseas?
The career opportunities at Allseas depend on your previous education. As a graduated Structural Design student, you can start at Allseas in the position of structural engineer. After a few years at the company, there are opportunities to become senior structural engineer. In this position, you provide advice and leadership at all levels, and guide and develop the junior structural engineers. After that, you can become a specialist or head of a specific unit. Allseas also makes it possible to switch disciplines and departments, for instance to become a project manager or proposals engineer. My personal ambition is to further increase my structural engineering knowledge and in the future use this knowledge to become an overall engineer. ◀

References:
[1] *http://allseas.com/equipment/pioneering-spirit/*

Figures:
Header,1,2,4 *Allseas Engineering B.V.*
3 *Milan Rinck*

Pioneering Spirit | Allseas
Pioneering Spirit (formerly Pieter Schelte) is a dynamically positioned vessel for single lift installation and removal of large offshore oil and gas platforms, and the installation of oil and gas pipelines. [1]

Figure 4: Pioneering Sprit at the Maasvlakte 2, Rotterdam

Interesting facts about Pioneering Spirit

- Length of 382 meters equal to 6 Boeing 747's or 31 buses;
- Surface of the main deck covers to 6 soccer pitches;
- Topsides lift system capacity of 48,000 metric tons (mT) equal to 6 Eiffel Towers;
- Ballast capacity of 700,000 metric tons equal to 280 Olympic swimming pools;
- Length of cabling 2,300 kilometer the distance between Delft and Moscow;
- 2.5 million liters of paint used for the hull;
- Total cost to build 2.6 billion euros;
- Some 600 Dutch companies worked on the development and construction;
- The amount of meals served daily is 1,580;
- The ship has aquariums on-board to prove that the ship barely moves under the influence of high waves.

Technical facts Pioneering Spirit

- Length overall (incl. stinger): 477 m
- Length overall (excl. stinger): 382 m
- Length between perpendiculars: 370 m
- Width: 124 m
- Depth to main deck: 30 m
- Slot length: 122 m
- Slot width: 59 m
- Topsides lift capacity: 48,000 mT
- Jacket lift capacity: 25,000 mT
- Operating draught: 27 m
- Maximum speed: 14 knots (26 km/h)
- Total installed power: 95,000 kW
- Thrusters: 12 x 6,050 kW
- Accommodation: 571 persons
- Deck cranes:
    - Special purpose crane of 5,000 metric tons
    - Special purpose crane of 600 metric tons
    - 3 pipe transfer cranes of 50 metric tons
    - Pipe cargo capacity on main deck 27,000 metric tons

Boerenwetering garage, Amsterdam

Geotechnical Risk Management

By: Jacco Haasnoot & Arjan Wisse (CRUX) and Maarten de Jong & Phil Rickes (Max Bögl)
CRUX Engineering BV & Max Bögl Nederland BV

In order to improve the quality of life and reduce parking problems in the "Oude Pijp" in Amsterdam, the underground parking garage the Boerenwetering is constructed. This underground parking lot has a capacity of 600 parking places. As a result, it is possible to reduce the number of parking places on the street by about 300. This is favourable for the pedestrians, cyclists, and the neighbourhood in general.

The header shows an impression of the Boerenwetering garage. The garage is constructed beneath/in the existing canal between the Hobbemakade and the Ruysdaelkade, close to the Rijksmuseum. The garage consists of two parking layers on top of which the canal will be reestablished.

The parking garage Boerenwetering is constructed within a deep excavation, enclosed by sheet pile walls. The length of this large pit is about 260 meters and the width is 30 meters. The sheet pile walls are also part of the permanent retaining walls of the parking garage. The building pit is constructed with one layer of struts and an underwater concrete floor. The underwater concrete floor is anchored with GEWI-anchors, which are applied vibration-free in order to minimise the hindrance for the surroundings. The distance between the sheet pile walls and the buildings at the Hobbemakade is about 20 meters, while the distance between the building pit and the buildings along the Ruysdaelkade is 8 to 9 meters.

Soil profile and groundwater
The surface level at the project location is NAP +0.5 meters. The soil is a typical Amsterdam soil profile. In other words, the top layer consists of anthropogenic sand. This is followed by Holocene deposits, i.e. peat, clay, a tidal silty sand and clay layer, and the basal peat layer. Below the Holocene deposits, the first Pleistocene sand layer is found at a depth around NAP -12 meters. The phreatic water level is NAP -0.4 meters, which is equal to the level in the canal. The piezometric level in the first Pleistocene sand layer is NAP -2.5 meters.

Geotechnical Risk Management
The lessons of Geotechnical Risk Management (GeoRM) are applied to minimize the risks of damage on existing and new structures in this project. GeoRM is one of the results of the comprehensive Dutch Geo-Impuls program for reducing geotechnical failure by 50% (2009-2014). The following approach was followed:

1. Determine the structural and foundation conditions and resistance of adjacent structures. Requirements are imposed by the nearby structures and various parties, such as building owners or service companies.
2. Predicting deformations, vibrations, and groundwater level changes due to construction works.
3. Determine the expected damage risks; relate steps 1 and 2.
4. Take preventive (design) measures when requirements are not met. This will lead to a final design that

meets the criteria. A monitoring program is defined to check whether these criteria are also met during construction.
5. Monitoring; compare prediction with measurements during execution (observational) in each relevant construction phase.
6. Take correction measures when measurements exceed the prediction. Define the measures in the design process.

These six steps are incorporated in the complete design process for the parking garage Boerenwetering.

Risk assessment - vibrations

Two main sources of vibrations are defined in this project; vibrations caused by vibrating the sheet pile walls into the ground and vibrations caused by passing construction vehicles.

CRUX has taken the following systematic steps to determine possible damage to surrounding buildings due to vibrations:

- Predict vibration intensity at the location of nearby buildings due to installation of the sheet pile walls (in accordance with the calculation procedure described in CUR166 3rd edition);
- Conduct a vibration test of passing (construction) vehicles, before the construction works and during the construction works;
- Check the vibration intensities to the Dutch guideline SBR-A (for damage to buildings).

The vibration measurements prior to the start of construction show that the SBR criteria are met in the initial state. When this would not be the case or when limit values are exceeded during construction, the most effective correction measures are a speed reduction and/or levelling of the pavement.

Predictions of the vibration levels during the installation of the sheet pile walls show that the sheet pile walls can be vibrated into the ground at the (side of the) Hobbemakade, where the distance between the buildings and the pit is relatively large. At the (side of the) Ruysdaelkade, however, this distance is too small, which led to the choice for the press-in method. Monitoring during construction proved that the prediction was correct.

Figure 1: Installation of sheet pile walls at the Ruysdaelkade

Building pit design

Sheet pile walls

Two different types of sheet pile walls are used during construction of the building pit. Along the Ruysdaelkade, AZ 26-700N profiles are used, which are pressed into the soil (*Figure 1*). Due to this method, deformations and vibrations are minimized. Along the Hobbemakade and the short sides of building pit, AZ 18-700N profiles are vibrated into the soil. The earlier mentioned sheet piles are placed 1 meter into the first Pleistocene sand layer, i.e. installed at NAP -13.5 meters to -14.0 meters.

The excavation depth within the building pit is NAP -10.6 meters. In order to ensure stability of the building pit during excavation, a layer of struts is placed at a depth of NAP -2.5 meters. These struts are placed under water using divers. This means that the first 3 meters are excavated without support. The deformation of unsupported sheet pile walls is relatively difficult to predict as they are sensitive to a change in load and/or support. At the Ruysdaelkade in particular, this means that a load restriction is set on surface level. Too much deformation in this phase will result in additional deformation in the deepest excavation stages. Therefore, it is of importance to control the deformation in the early excavation stages. To control the deformation, two measures are taken:

1. A stiffer sheet pile wall is applied at the Ruysdaelkade side.
2. The struts can be prestressed when they are positioned. Whether the struts will actually be prestressed, will be decided based on the monitoring data (observational method).

Underwater concrete floor

The excavation of the building pit is a so-called wet excavation. This construction method is also favourable regarding deformations. The largest part of the load that a sheet pile wall has to resist originates from the difference in water level. During the wet excavation stages, there is no difference in water level. Once the underwater concrete floor is installed, the sheet pile wall will be supported at two levels in a structurally favourable way, minimising the deflection of the wall when it is fully loaded. Another advantage is that the risk of influencing the water levels outside the building pit is minimized because the water is drained from the pit once both a vertical and horizontal barrier is in place.

The underwater concrete floor is 0.9 meter thick and lies on a 0.3 meter thick gravel layer. The gravel layer contributes to a potential control of the upward water pressure beneath the underwater concrete floor. The larger part of the upward water pressure is counterbalanced by GEWI-anchors.

Struts

The struts are constructed from 1,020 x 15 millimeters tubes with 5.32 meters spacing (*Figure 2*). Normally, the struts are not prestressed. The necessity of prestressing follows from the risk assessment. Prestressing is necessary when the limit value for deformations of the sheet pile wall is reached in

Figure 2: Placing the struts

the first excavation phase. When the limit value is reached, a prestress force up to 250 kN/m can be applied.

The building pit was designed in close cooperation with all parties involved in the pit construction. Involvement in an early stage of all parties is a risk measure in itself. Issues that are solved in the 'construction pit team' are (among others):

- Relation between columns, pile grid, and strut center to center distance;
- Effect of a change in pile loads (tension to pressure load) in relation to the pile grid;
- Fibers added to the underwater concrete in relation to reinforcement cages in the underwater concrete;
- Tolerances in the struts in relation to the installation of sheet pile walls and known obstacles.

Deformations

The main source of ground deformation is the deflection of the sheet pile wall during excavation. The deformation due to excavation of the building pit are predicted with the finite element (FE) software PLAXIS. *Figure 3* shows an example of the model used.

The damage assessment of the design, in order to arrive at a final design, was performed using the Tensile limiting strain method by Netzel (2009).

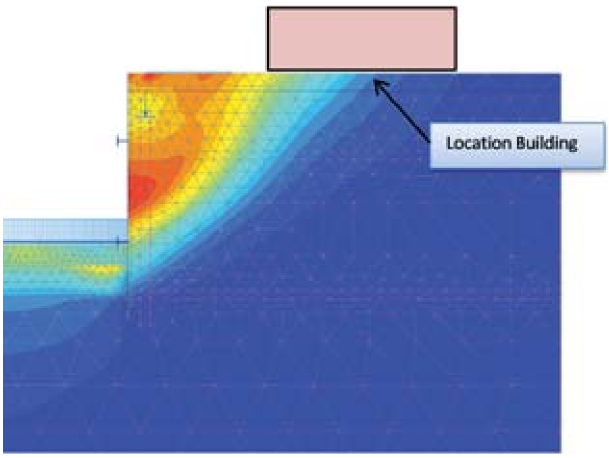

Figure 3: Impression of the deformation contours calculated in PLAXIS in the final excavation phase

Monitoring

The objective of monitoring during construction is to gather monitoring data in different construction phases, with respect to developments in deformations, vibrations, sound levels, air quality, and ground water level changes in and around the construction site. Monitoring enables the possibility to anticipate when the measurement data is likely to exceed the previously determined limit values.

Monitoring plan

In this project, the following aspects are monitored:

- Deformation of the surrounding objects;
  Objects surrounding the site include: buildings, bridges, sewer pipes and the quay walls along the Hobbemakade and the Ruysdaelkade. Deformations of these objects are measured by precise levelling on measuring bolts attached to the buildings and bridges (see *Figure 4*).
- Monitoring of cracks in surrounding buildings;
  In case there are cracks on the surrounding buildings and bridges, prior to the construction, crack gauges are placed to monitor movements in the cracks.
- Horizontal deformations of the sheet pile walls;
  Deformations of the sheet pile walls are measured with inclinometers and with x,y,z measurements of the top of the wall (see *Figure 4*).
- Vibrations on surrounding buildings;
  As discussed before.
- Water levels;
  The water levels are measured with stand pipes in the surrounding area. All three piezometric levels are monitored: the phreatic level, the tidal sand deposit level and the first sand layer.

Figure 4: Impression of the number of precise levelling points around the Boerenwetering garage

Status of execution

At the moment of writing this article, the struts are in place and deep excavation has just started. Monitoring has shown that the deflection of the sheet pile wall and also the deformation of the building are within the predicted limits. This means that prestressing is not necessary.

The Boerenwetering garage is expected to open to the public at the end of 2017. ◄

Figures:
Header, 1-4 *CRUX Engineering BV & Max Bögl Nederland BV*

Onshore wind turbines

By: J.E. (Jurgen) Cools MSc.
Geotechnical specialist at Royal HaskoningDHV, the Netherlands

In the Netherlands, as well as internationally, many onshore large scale wind farms are being constructed or developed. For these wind farms the machine size and rated power increase continuously (*Figure 1*). The consequence of this development is the increase of vertical and shear loads at the tower base, along with significant overturning moments. Large foundations are needed to resist these dynamic loads. The design of the large foundations is complex compared to building foundations. Besides the significant loads, the design includes the selection out of numerous codes and standards, found action methods, calculation methods, and design models, ranging from basic to advanced. For this reason the understanding of the geotechnical investigations and design are becoming more and more important to achieve a safe and economical foundation design.

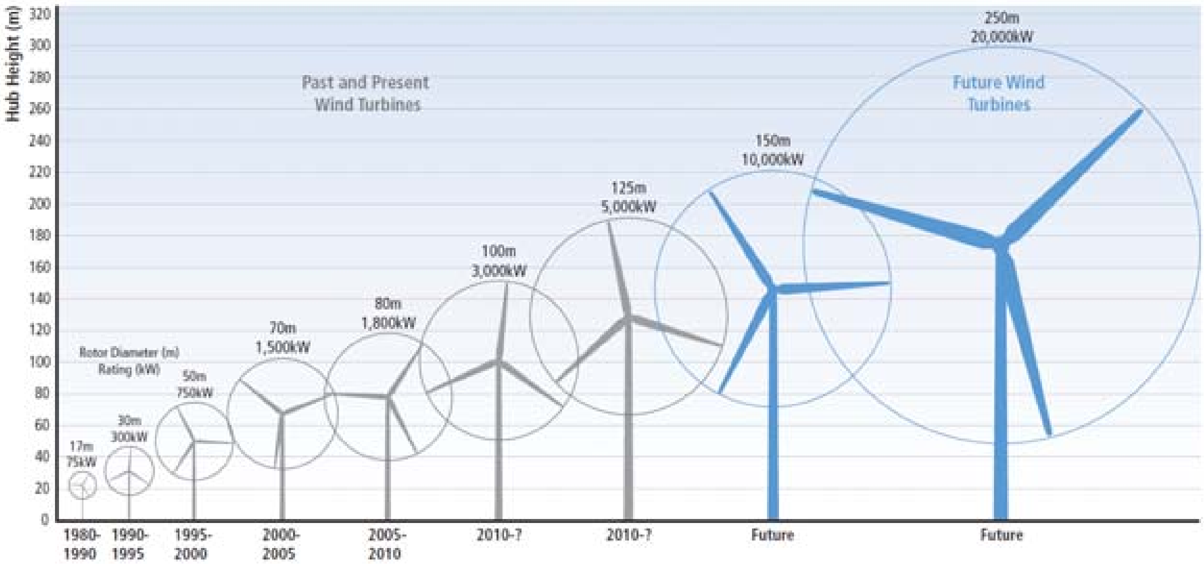

Figure 1: Growth in size of typical commercial wind turbines [1]

Foundation types

Figure 2 shows various foundation methods for onshore wind turbines. The selection of the best applicable foundation type depends mainly on the geotechnical conditions. The subgrade strength and stiffness of the soil or rock need to be sufficient to resist the cyclic and dynamic wind loads.

A spread footing, or gravity foundation, can be considered as the simplest foundation type. The spread footing is placed directly on the foundation soil or rock. The most efficient form is a circular footing with a tapered cone. The weight of the concrete and optional overburden provides resistance against the overturning moments. At locations where strong bedrock is encountered near the surface, post-tensioned rock anchors can be applied to reduce the dimensions of the cap foundation significantly. The rock anchors must be designed for fatigue. In regions where competent soil or rock is found at shallow depth, the overlying weak or compressible soil can be improved. Many techniques for improvement are available and depend on the type and thickness of the soil to be improved.

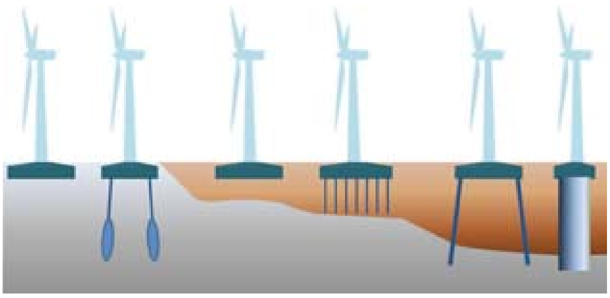

Figure 2: Various foundation methods for onshore wind turbines

Pile and cap foundations are used in regions where the competent soil or rock is encountered at much greater depth. This foundation method is most commonly used in the Netherlands. *Figure 3* shows an example of the construction of a pile foundation. The overturning forces on the cap foundation are being transferred to the piles as compressive and tensile axial loads. The piles transmit these loads to the ground via a combination of friction and end bearing. Lateral loads are resisted through lateral earth pressures on the piles. Battered piles are often required to increase the lateral foundation stiffness and to increase the pile bearing capacity.

Figure 3: Example of the construction of a pile foundation

Design guidelines, codes and standards
The most commonly used design codes and guidelines for wind turbine foundation design are:

- IEC-61400-1 Wind turbines - Design requirements [3];
- DNV/Risø Guidelines for Design of Wind Turbines [4];
- GL Guideline for the Certification of Wind Turbines [5];
- Eurocode 7: Geotechnical design of structures - part 1: general rules [6].

Besides these guidelines, local codes and annexes (e.g. the Dutch NEN-EN) are also applicable. Requirements for the foundation design are often specified by turbine manufacturers in technical documents. Because of the differences between standards, guidelines, and specifications, it is important that the designer is aware of any conflicts or omissions.

Limit states
In accordance with Eurocode 7 and the GL guidelines, the design needs to be checked for the ultimate limit state (ULS) and the serviceability limit state (SLS).

Geotechnical design criteria
Some of the most important design criteria that are specified in codes, guidelines, and technical documents are briefly described below.

Rotational foundation stiffness
For both spread foundations and pile foundations, one of the main design criteria for foundation design is the rotational stiffness. In order to avoid excessive motion at the tower top and to provide the required damping, the turbine manufacturer always provides a minimum rotational stiffness value. The final foundation design must satisfy this minimum value. Typical minimum values of the rotational stiffness are 60 to 120 GNm/rad. The rotational stiffness depends on the stiffness of the foundation structure and the subsoil. In case of a spread foundation, often an infinitely rigid foundation block is assumed, so that the rotational stiffness only depends on the dynamic shear modulus G of the subsoil, and hence of the dynamic modulus of elasticity E_{dyn} and the Poisson's ratio v. For pile foundations, the rotational stiffness depends very much on the cyclic spring stiffness of the piles. A typical value for the minimum required cyclic spring stiffness is about 200 MN/m.

Gapping
The GL guidelines describe ground gap limitations for the foundation design. The ground gap criterion requires that, under specific IEC normal operational design load cases, no ground gap (i.e. zero contact pressure) shall occur at the foundation-soil contact. This means that in these cases, the entire foundation footprint must remain in compression. This gapping limit acknowledges that in the case of a spread foundation, the rotational stiffness decreases non-linearly after foundation uplift (zero contact pressure). Besides this, in certain soil conditions, a limit on gapping will also ensure that soils subjected to cyclic degradation are prevented from experiencing multiple instances of zero pressure which, in the presence of water, could lead to breakdown of the in-situ soil structure and subsequent related serviceability problems [8]. For unfactored loads (SLS) under specific operational conditions, it has to be proven that the eccentricity e of the total vertical load is less than 25% of the radius: $e < R/4$. Commonly, for unfactored (SLS) extreme loads, no more than 50% of the base area may be without compression. It has to be proven that: $e < 0.59 \times R$.

Horizontal stiffness
For a pile foundation, a minimum horizontal stiffness is required by the turbine manufacturer. Often the minimum value depends on the total mass of the wind turbine and its foundation, or on the rotational stiffness. Typical minimum values of the horizontal stiffness vary between 500 and 1,000 MN/m. It should be taken into consideration that the lateral soil reaction should be reduced due to the cyclic load. This reduction can be up to 10% for sand and 30% for clay (according to DNV guidelines).

Overall stability
For spread foundations, it must be verified that the overall stability is sufficient. This is particularly relevant for footings placed on or near sloping ground. For spread foundations on rock, the overturning stability should be checked for the

extreme loads in the ULS. According to the GL guidelines and Eurocode 7, the safety is guaranteed by verification of the bearing capacity of the subsoil.

Tilt

The foundation shall be designed to minimize settlements and especially differential settlements. Deformation criteria are often specified by the turbine manufacturer. Generally for wind turbines the following must be kept strictly:

- A maximum inclination of 3.0 mm/m resulting from the characteristic extreme load;
- A maximum unequal settlement of the foundation of 1.0 mm/m from the characteristic operational load.

Settlements are not governing for design in case of spread foundations on dense soil or good rock, since (average) contact pressures from vertical loads are typically quite low (e.g. 50 to 75 kPa).

Foundation loads

Wind turbine

Generally, wind turbine foundations are subjected to vertical and shear forces along with significant overturning moments. These overturning moments are principal for foundation design. The hub height and rated power often influence the overturning moment. Design loads of the tower are provided by specialists of the wind turbine manufacturer in a load document (or technical specifications) that satisfies all load cases as outlined in the IEC 61400 standards. A distinction is made between operational loads, extreme normal loads, extreme abnormal loads and fatigue. The operational loads are cyclic loads caused e.g. by low wind speeds of 5.0 m/s or starting and stopping of the wind turbine generator. The extreme loads have a low probability of occurrence, but result in high design forces at the tower base. Examples of extreme winds are 1-in-50 year three second gust or turbine emergency stops. The extreme loads can be considered as dynamic loads. It depends on the turbine type and site specific wind conditions which design load calculation is governing for foundation design.

Buoyancy

The foundation design shall take into account the vertical hydrostatic pressure (buoyancy). The upward water pressure can be regarded as a negative stabilizing load or as a positive destabilizing load. The designer should be aware of the effect of buoyancy for various limit states.

Ground investigation

Eurocode 7 and the DNV guidelines provide recommendations for the scope of the ground investigation. Turbine manufacturers often provide additional specifications for ground investigation. Generally the soil investigations consist of the following parts:

- Geological desk study;
- Geotechnical investigations;
- Geophysical survey (optional).

A geological desk study should be performed first to establish a basis for selection of methods and extent of the site investigation. A geotechnical investigation may consist of trial pits, borings, in-situ testing, soil sampling, and laboratory testing. For pile foundations in the Netherlands at least three Cone Penetration Tests (CPTs) should be performed for each wind turbine location, combined with one borehole in the center point of the structure. For spread foundations on soil or rock, it is sufficient to perform at least two borings or CPTs for each location, of which one is performed in the center point of the wind turbine. Geophysical survey can be used to extend the localized information from borings or CPTs. The results give a better understanding of the stratigraphy within the considered area.

Conclusions

Due to the continuous developments in the wind industry it is expected that loads imposed on wind turbine foundations will also become larger. This requires a clear understanding of the driving considerations for geotechnical design.

Due consideration should be given to the following matters:

- The extent of the geotechnical investigation should be based on a geological desk study and comply with the Eurocode 7 and the GL guidelines. For difficult soil or rock conditions geophysical survey is preferred to extend the localized information from borings and CPTs;
- Based on the encountered ground conditions, the most appropriate foundation method should be selected, that meets the stringent design criteria. Principal design criteria for design of spread foundations are ground gapping and the maximum permissible settlement and tilt. For pile foundations, the principal design criterion often is the rotational stiffness;
- Wind turbines should be regarded as structures, other than buildings, for which in specific IEC 61400 standards exist. These standards are however lacking specific design guidelines for wind turbine foundations. The DNV guidelines explicitly address the design of wind turbine foundations. These guidelines are well applicable for spread foundations; for pile foundations, the design methods provided in Eurocode 7 are preferred. The methods in the DNV for pile foundations comply with the API standards. ◄

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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

Offshore turbine installation

Monopile gripper frame

By: Arnold de Jager
Project Engineer at Temporary Works Design BV

The creation of permanent offshore works, either floating or fixed, often requires additional structures to enable transportation and installation. This can range from some load spreading wooden mats and lashings to place some simple cargo on a vessel, to a multi-functional gripper that enables controlled placement of large foundations within tight tolerances. Temporary Works Design (TWD) is specialized in the design of such structures and tools that help their clients finish their permanent works projects safely and on time.

The main challenge of many projects is to handle the loads of foundations or cargo weighing up to, and sometimes way over 1,000 metric tons. To ensure predictable load paths, it is preferred to have a statically determined design. As a result, concentrated loads from the cargo need to be transferred to a vessel or other superstructure/foundation. This can roughly be compared to planking on a cardboard moving box. With the ever increasing weight of foundation structures, this task proves to be increasingly challenging.

Figure 1: Van Oord monopile gripper

Offshore wind is an important sector where TWD assists many clients with the entire process of installing an offshore turbine. In particular monopiles require some innovative seafastening and handling solutions. Monopiles are big steel cylinders with a length of 70 meters and a diameter of seven meters, weighing between 700 and 1,400 metric tons, and serving as the foundation for a wind turbine or substation. Generally, these monopiles are transported in horizontal orientation on a vessel and will subsequently be 'up-ended' to its vertical position and placed on the seabed. By either a hammer or through vibrations, the pile is then embedded into the soil to form a rigid base for the turbine. TWD provides designs and tools for each phase of the process, including the placement of turbines and power cables.

An absolute showcase of the challenging requirements and advanced capabilities of temporary works includes Van Oord's monopile gripper frame, shown in *Figure 1*. The gripper is designed to keep monopiles in the correct position and inclination. Inclination should generally be within 0.25 degrees from vertical position, and the axial orientation within a few degrees to allow the sturdy power cables to enter the pile. To achieve such accuracy, the gripper needs to counteract the environmental loads from waves, wind, and current acting on the pile during lowering and hammering. Loads of up to 200 tonnes can occur.

The Van Oord gripper is designed to handle a range of monopile sizes, is able to rotate them, and correct their position within a 3 by 3 meter working envelope, see *Figure 2*. The system can work at deck level, or can be jacked down 6 meters to guide piles as far down as possible, due to the integration of the structure in the

Figure 2: The gripper that holds the monopile in position

vessel. Walkways and railings around the gripper allow it to be used as a working platform, also at intermediate levels. For transit, the frame is folded by a winch and skidded inboard. The multi-step jacking and skidding processes are fully automated using integrated position sensors.

In total, two nearly identical grippers have facilitated the installation of almost 200 wind turbines so far and will be used for several more wind parks in the upcoming years.

Motion compensation systems

Due to the work for many different clients, TWD can signal broader concerns within the industry. One such observation involved the dangers as well as the extensive amounts of time required to perform lifts from a floating vessel. Following this insight, TWD developed an innovative solution: the motion compensated platform 'Barge Master T700' (*Figure 3*). This platform can compensate the hook motions of a 400 metric tons crane, or alternatively, compensate supply loads of 700 metric tons up to a significant wave height of 2.5 meters.

After the launch of the Barge Master in 2008, this business unit split from TWD and continued as a separate entity, specialized in the development of motion compensated systems to improve the safety and workability of offshore operations. Barge Master's portfolio now also includes a motion compensating pedestal crane of 20 metric tons and a gangway with a 1 metric ton auxiliary crane capacity.

Figure 3: Barge Master T700

Motion compensated pile gripper

Due to the tight tolerances required for wind turbine installations, a Jack-Up Barge (JUB) or vessel is normally used to install the foundations and turbines. They create a fixed offshore working platform, eliminating vessel motions. Since these advanced vessels typically have a higher day rate than normal crane vessels or barges, it would be much more cost-effective to perform such installations without having to create a fixed working platform. An added benefit would be that seabed soil conditions do not affect the ability of the vessel to perform its installation job.

Figure 4: Motion compensated pile gripper

Anticipating the demands in the future offshore wind market, TWD and Barge Master have combined their strengths to develop a new product: the motion compensated pile gripper. In addition to the already advanced functionalities of a regular gripper, this version should also be able to anticipate and counteract dynamic vessel, pile, and crane motions. ◄

Figures:
Header, 1-4 Temporary Works Design BV

Temporary Works Design

Temporary Works Design (TWD) is an engineering firm specialized in the design of temporary works; structures that facilitate the construction of permanent works. Working from concept to detail, we provide custom designs and fabrication services for the offshore and civil markets. Flexibility, practicality and creativity are the driving forces behind each of our designs.

"Innovation comes when a client's needs are met with a forward thinking solution."

TWD is a young and growing company. On the work floor, we encourage a fun, fast-paced, enterprising and open atmosphere. We work hard to finish projects before their deadlines, but we take the time to mingle over lunch together and to join in on corporate events. Our determination to promote innovation has attracted a young, international team, with an average age of 30. To develop this young team, we take a proactive role in the continued development including: personal coaching; in-depth software courses; technique-specific workshops; lessons learned meetings; and site visits.

Waterpioneers of the Netherlands

Design of floating buildings

Interview with: Rutger de Graaf & Jelle Veder
Co-founder of Blue 21 & co-founder of Bartels & Vedder BV

By: Eline Dolkemade & Thomas van Vooren
Editors KOersief

Since approximately 70% of the earth's surface consists of water, we will run out of land to build on at some moment in the future. Therefore, floating buildings are gaining interest all over the world. In the beginning of this relatively new area of structural design, these floating buildings were designed as if they would be built on land. This is a mistake with serious consequences. For example, a floating house in IJburg was finished and placed in the water. It was levelled perfectly horizontal, but when the daughter of the owner walked in, the house was out of balance immediately. This house had a center of gravity that was relatively high and a foundation that was rather narrow, considering the height of the building. This issue happened a several times to floating structures with a wrong design approach.

Design approach

The structural design of floating buildings should not be underestimated. A broad spectrum of knowledge regarding the structural, ecological, social, and financial aspects is required for the design of floating buildings. It is both important and efficient to gather all this knowledge in an international network.

Figure 1: Render of a floating city

One of the guests for this interview is Rutger de Graaf, co-founder of Blue 21; a social enterprise and collaboration platform that gathers all kinds of knowledge, required to design floating cities. This knowledge is currently focused on realizing urban expansion with living, working, recreation, and infrastructure in the public space, all on water. The other guest for this interview, also member of this international network, is Jelle Vedder; co-founder of Bartels & Vedder BV; a company with extensive experience in engineering floating buildings.

Floating foundation

The engineering of a floating structure is different from that of a structure on land. One of the differences is the foundation. Generally, two types of foundations can be distinguished: a solid foundation and a floating basement structure. Various materials can be used; however, concrete is mostly used, because it is relatively inexpensive. For heavier buildings, lighter materials are applied, such as aluminium or glass fiber composite. The latter is used in a project of floating houses in Delft.

Most houses in this project are designed with a concrete basement structure, however, one of the owners wanted his house full of aquariums, which leads to a higher total weight in combination with an already heavy foundation. The solution was a basement made out of glass fiber composite. In addition to the low weight of the material, glass fiber composite is convenient for building sites that are difficult to reach and it has more versatility with shapes, compared to concrete. Glass fiber composite elements can easily be glued together on the building site. The light material causes the basement structure to float in the beginning. To add more weight, a concrete floor is casted on the bottom of the basement. In this situation, the basement functions like a formwork for the concrete. This creates a lower center of gravity, which is positive for a floating structure.

Figure 2: Steel structure of a floating house built in land

NTA 8111
Since designing a floating house is totally different from designing houses on land, the Eurocode is not sufficient. To cope with these unusual conditions and other regulations, the NTA 8111, Dutch Technical Regulation, is established. These regulations are used by governments to approve design proposals. Structural engineers use these regulations for the design of the structures. One item in the regulation considers the stability of the design. We have taken out a few interesting demands:

- The first demand considers the metacenter. The metacenter determines whether the floating structure has sufficient stability. The floating structure is stable when the metacenter is positioned above the center of gravity of the structure;
- A second demand considers the draft and heeling of the structure. The draft can be determined from several load combinations. The most unfavourable combination is governing. Besides the draft, the intensity of heeling is determined by several moment combinations caused by wind loading, wave loading, several kinds of horizontal loading, and the second-order effect;
- The third demand considers the distance of safety. This is the distance from the water line to the top of the floating structure (the distance is illustrated in *Figure 3* with the symbol 'V'). The distance of safety has to be at least 300 millimeter;
- The final demand considers the maximum slope of the structure. This is determined by overturning moments. Beside that, there are also some demands related to nautical investigation.

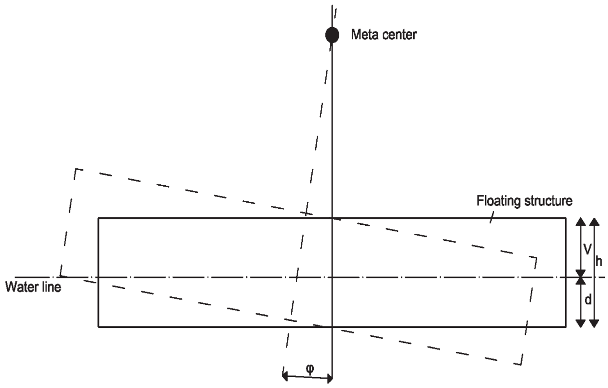

Figure 3: Positioning of the basement

Environmental conditions
Where wind is one of the most important loads for buildings on land, more environmental conditions have to be taken into consideration for floating structures. Examples of these conditions are ice-formation, intensity of wave-action, the type of current, and the water level. These conditions can have more impact than often thought. Ice-formation, caused by current or strong wind, in a river or lake can cause high additional horizontal loads on the basement walls that would normally be desined to only resist the horizontal water pressure. Another example is the intensity of current. This intensity can influence the method of anchoring of the structure. Except for these extreme situations, the comfort of the daily situation is also important. These regulations can also be found in the NTA 8111.

Jelle Vedder studied mechanical engineering before he studied general management at Neyenrode University. He specialized in innovative solutions and therefore he and a fellow student started a company in developing innovative solutions for technical companies. They taught companies to think out of the box. After this company, Jelle led a company specialized in foundation techniques. His youngest company was founded in collaboration with Chiel Bartels. Bartels & Vedder is a structural engineering and consultancy company for innovative solutions in the building industry.

Financial differences

How do the costs of a floating house compare to the costs of a house on land with equal floor area? The price of a house is mostly dependent on the location, similar to the house market on land. Generally, a floating house is about 20% more expensive than a house on land. Jelle tells us that the target group is willing to pay this larger amount of money to live on the water.

Figure 4: Floating houses in the Harnaschpolder in Delft

Water shows no mercy

The software required for these projects on water is different from the calculation and design programs we know. They are similar to the modeling and design programs used by naval engineers in the ship-building industry. Issues like the position of the center of gravity, geometry and the draft are very important for both

"Water shows no mercy, you will notice every single kilogram that is placed wrong."

design areas. Therefore, Bartels & Vedder have developed their own models to calculate these problems. These are also used for second order calculations, which are very important for floating structures and hard to simulate in standard calculation programs. If a building tilts a little, other weights, such as facades, move along because the neutral line shifts. In these models, every window, beam, etc. is modeled with real dead loads with respect to the x-, y-, and z-axis. Therefore it can be determined whether a building will follow the tilt or if it stops when subjected to differently angled loads. Second order effects, in combination with a too high center of gravity, were sometimes underestimated by several engineering companies in the past. Jelle states that the distribution of loads over the foundation has to be perfectly balanced: 'Water shows no mercy, you will notice every single kilogram that is placed wrong'.

Figure 5: Floating cities in the future

Rutger de Graaf studied Civil Engineering at the University of Technology in Delft. He finished both his MSc and PhD degrees cum laude. His PhD research was devoted to the question "How can cities use water to be more durable and self-sufficient?". After his PhD, he won an international price with some fellow students for a design and a vision of development for a floating city. With this price just in their pockets, the group was asked to design the Rotterdam pavilion (the cover photo at the beginning of the article). Rutger is director and founding partner of DeltaSync, a leading international floating urbanization specialist, and co-founder of Blue 21, an interdisciplinary expert collaboration platform that aims to inspire the society to realize floating cities with a positive impact on the planet.

Tips for the future structural engineers

The design of floating buildings is currently a small market in the Netherlands, and also in the rest of the world. However, it is certain that we will see more of these projects in the future. We will definitely hear more from both of these companies which belong to the water pioneers of the Netherlands. This new market provides room for innovative solutions. One day, Jelle and Chiel had the idea to use existing Holcon floors as a floating foundation. With some adjustments, this product is currently a frequently requested structural system. Rutger and Jelle have come this far by constantly developing their products, anticipating to possible new markets, high persistence, and thinking 'out of the box'. We asked Rutger and Jelle for some tips for us, being a new generation of structural engineers. They say the most important qualities, which they sometimes miss in structural engineers these days, are persistence and thinking out of the box. We have the open mind and skills to create new possibilities and do not have to stick to the current traditional technology and design approaches. They say if we, new young structural engineers, will develop these qualities, we can realize great things. ◀

Figures:
Header, 1-5 *DeltaSync & Blue21*


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Future proof dry dock design

Diaphragm walls dry dock Alblasserdam

By: Lieneke van der Molen
Editor KOersief

A dry dock is a stationary construction or repair site for ships, boats, and other water craft. Using a mechanical pump installation, the dry dock is either flooded with or drained from water, which allows ships to enter and lay dry during construction. Between 2013 and 2014 a dry dock was built by Cordeel Nederland BV in Alblasserdam, the Netherlands. Fugro was involved from the start to the end of the project and responsible for the soil investigation, geotechnical engineering (foundation piles and retaining walls), and monitoring.

Fugro provides the people, equipment, expertise, and technology that support the exploration, development, production, and transport of the world's natural resources. The dry dock in Alblasserdam is an extraordinary project due to its dimensions and several design challenges such as the application and multifunctional use of the diaphragm walls, the interaction between the individual foundation elements, and the future ambitions of the contractor to build a second dry dock. The dock is situated on the river the Noord and near a fire station. It is located at a distance of 80 meters from the A15 tunnel underneath the river and close to an embankment with houses on strip footing.

The project
The dry dock is required to offer sufficient space to finalize superyachts. Therefore, the dry dock consist of a structure with a height of 33 meters. A seven-story building with offices and workshop spaces is situated next to the dock. This building nearly stretches over the full length of the dock. The cross section of the structure is shown in *Figure 1*.

It was important to achieve a high quality and a certain speed of construction. This requested a closed construction pit, which offered a dry enviroment for the construction of the dock. The nearly dry environment was accomplished by the use of diaphragm walls that function as water retainers. A heavy foundation was made to resist the high loads on the floors and to guarantee horizontal stability. More project details are shown in *Table 1*.

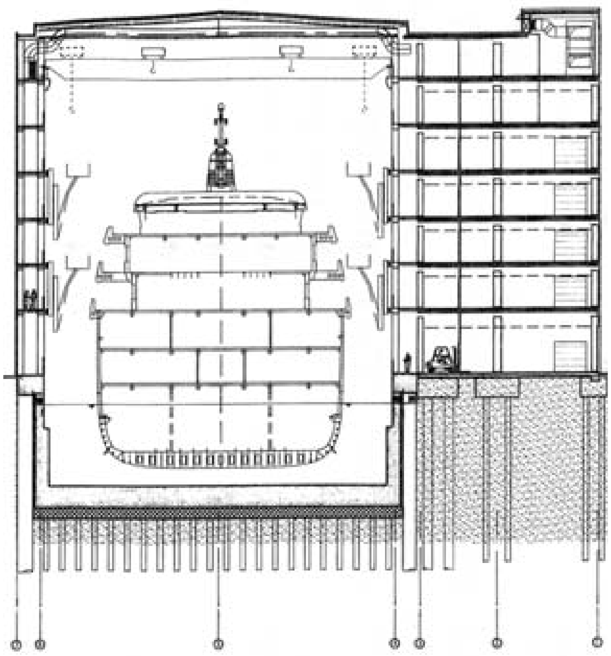

Figure 1: Cross section of the design

Table 1: Project data

Dimensions construction pit	
Length	165 m
Width	35 m
Depth	10 m below ground surface
Diaphragm walls	
Height	33 m
Thickness	1.2 m
Panel width	7.5 m
Level bottom-side wall	NAP -31 m
Number of joints	60
Total wall surface	10,000 m^2
Dry dock structure	
Thickness bottom wall	1.3 m
Thickness upper wall	0.8 m
Floor thickness	1.4 m
Piles	
Construction pit	1,100 piles vibro-combination pile pile tip at NAP -22 m
Office/Workshop building	450 piles prefab concrete piles pile tip at NAP -20 m

The construction started by making the diaphragm walls. This was done in multiple phases that allowed for simultaneous piling of the foundation piles, at a distance of at least 50 meters from the location of the diaphragm walls. After the construction of the walls and piles, the pit was excavated. Therefore, the diaphragm walls needed to be supported by a temporary framework. Once the dock's floor and the lower part of the walls were finished, this framework was removed again. Afterwards, the upper part of the dock walls was created. *Figure 2* shows the construction pit after the construction of the diaphragm walls, vibro-combination piles, and temporary supporting framework.

The dock is partly constructed in the already existing harbour of Alblasserdam. Before the diaphragm walls could be made, a small part of the harbor needed to be filled with soil. This was done using a temporary cofferdam, to ensure a stable situation.

Soil structure and water flow

For this project, multiple Cone Penetration Tests (CPTs) were performed. These showed that the top layer of the soil was a thick improved layer of sand, followed by a stiff clay layer at NAP -27 meters. This clay layer of Kedichem functions as a water retainer under the sand layer. At NAP -38 meters, a second sand layer could be found. Extra CPTs were performed after constructing a part of the diaphragm walls to check whether the excavation for the walls caused relaxation in the ground. Relaxation means reduction of soil properties; in other words, increased horizontal loads on the structure and larger settlements.

Before the construction of the dock started, the location and composition of the clay layer of Kedichem was mapped out by Fugro. Based on this map, the depth of the diaphragm walls were determined. To ensure the water retaining function, the end of the wall was placed with a certain depth in the clay layer at NAP -31 meters. The clay layer of Kedichem contained local thin layers of sand. At these locations the diaphragm walls were applied deeper. During the excavation of the construction pit, the soil layers were checked visually to ensure that the correct depth for the walls was chosen.

A ground water level of NAP +0.4 meter was taken into account during the construction phase. After completion a ground water level of NAP +2.9 meters was used.

Foundation

Two types of piles were used in this project: the vibro-combination piles under the dry dock and prefab concrete piles under the building. For the vibro-combination pile, a casing is piled into the ground from ground level, in which a prefab concrete core is hung on the correct level. Afterwards, the casing is filled with grout and pulled out of the ground.

In the operation phase, the diaphragm walls function as bearing structure. The calculated bearing capacity is 10% of the actual capacity. This lower value is taken since the foot of the wall stands on the clay layer of Kedichem. On top of that, it is not allowed to calculate with the maximum capacity as the diaphragm walls are regarded as drilled piles, which means that the deformation is rather large before the capacity is reached. Due to this limited point bearing capacity, a higher axial spring stiffness is found. Deformation analyses show that the spring stiffness of the diaphragm wall is equal to that of the vibro-combination pile.

Figure 2: Construction pit with temporary framework

A phased construction requires more attention to deformation and load transfer between segments of the structure, including non-linear behavior of the soil, diaphragm walls, and foundation piles. Using the finite element program PLAXIS, analyses were performed to determine the influence of the deformation of the diaphragm walls on the environment. The results showed that the foundation piles in the active zone of the diaphragm walls have a soil nailing function. The piles transfer the weight of the active wedge partly to the second sand layer, resulting in a smaller buckling deformation of the diaphragm walls, see *Figure 3*. This leads to a reduction of the horizontal deformation and moments in the piles. With a plain-strain model in Plaxis, an analysis was performed to determine the differences in vertical deformations between the building and the dock. The results showed that the vertical load of the roof above the dock was equally divided over the diaphragm walls and transferred to the piles via the dockwall, since the axial spring stiffness was equal. However, the weight of the building next to the dock, and its vertical displacements, caused the diaphragm walls to lower. This resulted in a reduced spring stiffness and therefore a non-uniformly distributed load.

Diaphragm walls

The diaphragm walls were designed in collaboration with Geelhoed Engineering. A spring model was made in DSheetPiling to determine the moments, shear forces, and vertical deformations. The cross sections, used for the diaphragm walls, are not symmetric across the dock. Different cross sections are calculated due to the differences in geometry and soil structure. This required interaction calculations in the spring model. An important parameter is the flexural rigidity (bending stiffness, EI). When the moment on a diaphragm wall increases, the stiffness reduces and vice versa. Thus, the stiffness of the wall is directly related to the moment acting on the wall. For proper insights in a realistic situation, an M-N-κ-diagram should be inserted for the stiffness. However, this was not possible in DSheetPiling. To achieve something similar, a proper interaction between the

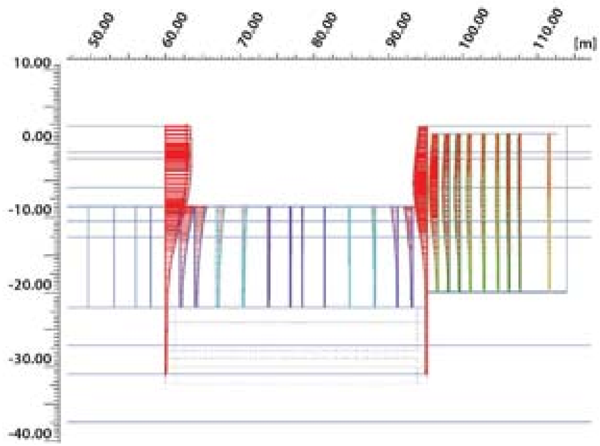

Figure 3: Deformations including soil nailing (right-hand side)

structural designer and geotechnical consultant is essential. During the design phase, much attention was paid to the quality of the diaphragm wall to ensure a reduction of water flowing in the construction pit. Therefore, the joints were monitored during construction. Tubes were casted along, in which measurement equipment could be installed. A water flow of 10 m^3/h was permitted. When it was suspected that a joint would not meet this requirement, grout was inserted at the outside of the joint. ◄

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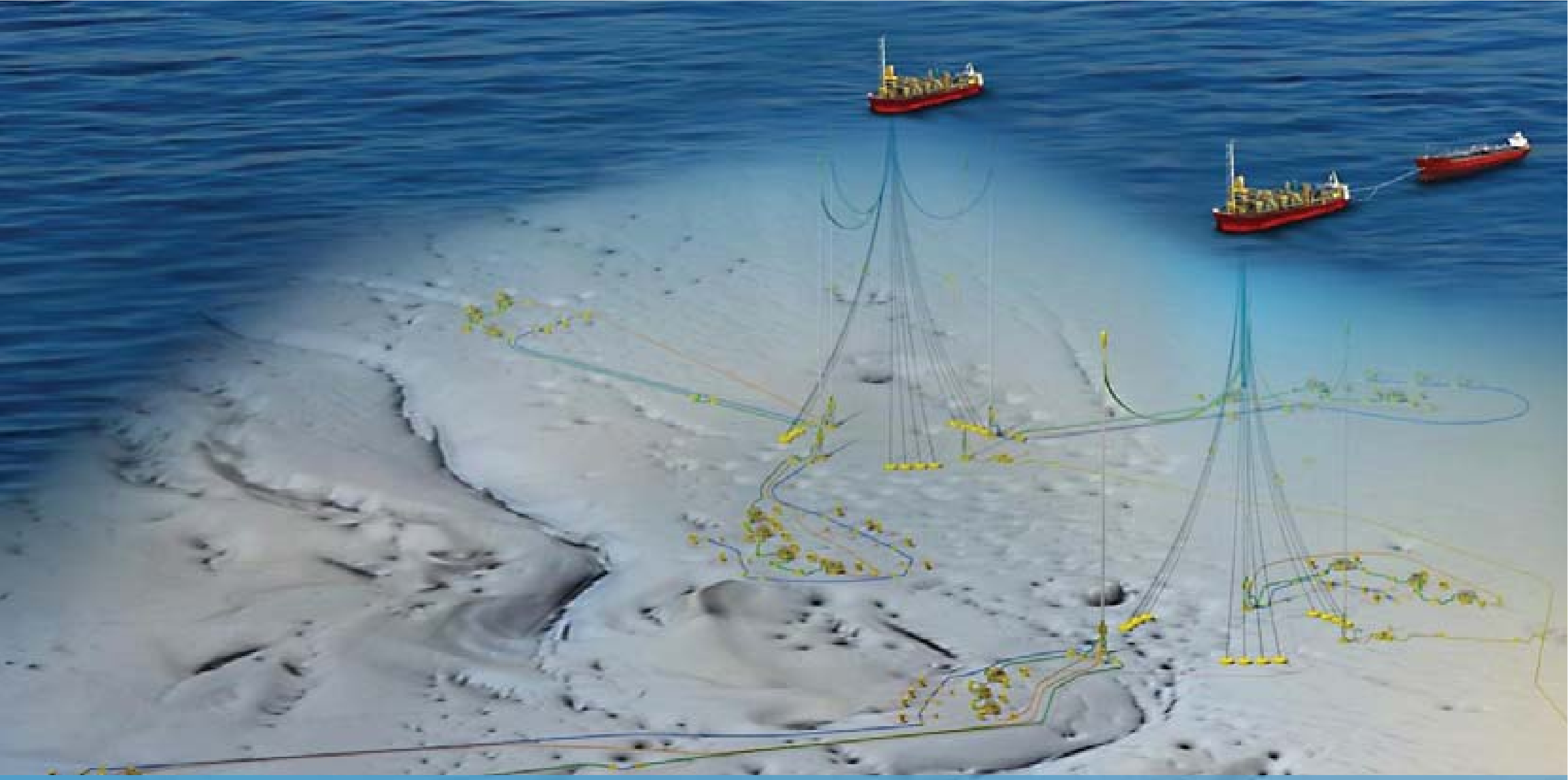
Figures:

Header, 1-3 *Fugro*



Furthering the oil industry's deep water reach

Kaombo Ultra-Deep Offshore Project

By: Caspar Breman
Specialist (RC) at Iv-Consult

The Kaombo Ultra-Deep Offshore Project will be a major step for the oil industry as it reaches new depths. This project involves the development of six oil fields, located 170 kilometers off the coast of Angola in water depths of up to two kilometers.

The SURF (Subsea Umbilicals, Risers, and Flowlines) contract was awarded by Total E&P Angola to the Technip Heerema Alliance in early 2014. It is an EPCI (Engineering, Procurement, Construction, and Installation) contract, meaning that the consortium is not only responsible for installation but also for the design, procurement, and fabrication of the various components included in the SURF contract.

As part of the integrated design team, Iv-Consult is responsible for delivering the design of the foundation of the Single Top Tensioned Riser (STTR) systems. The main purpose of these risers is to transport fluids from the seabed to two Floating Production, Storage, and Offloadings (FPSO's) moored above the oil fields (*Figure 1*). An FPSO is a floating vessel used for the production and processing of hydrocarbons and for the storage of oil. FPSO's are furthermore equipped with an offloading system, used to transfer the stored crude oil to shuttle tankers, which in their turn transport the crude oil to oil refineries. Therefore, this method does not require pipelines to transport the oil to the land.

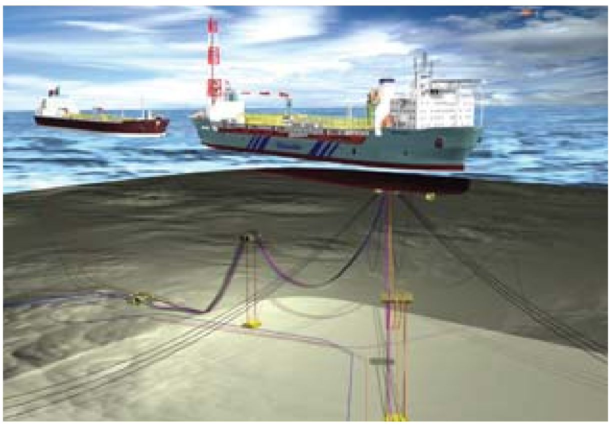


Figure 1: Floating Production, Storage and Offloadings (FSPO's)

The SURF contract consists of a total of 290 kilometers of pipeline and 115 kilometers of umbilical, which are cables that supply necessary control, energy, and chemicals to subsea oil and gas wells and any subsea system requiring remote control, such as a Remotely Operated Vehicle (ROV), used for the installation of the 'suction piles'.

'Suction piles' for the STTR system

The foundation system of the eighteen risers consists of suction piles (*Figure 2*), with a maximum weight of approximately 200 metric tons each. This foundation system is characterized by the fact that suction is applied in order to initiate penetration into the soft clay until the piles reach their target penetration depth. This process can also be reversed if needed to retrieve the pile in case of installation outside of the predefined tolerances. The design process started with the optimization of the aspect ratio, or the length versus width ratio of the pile. Soil behavior, weight and size optimization, and installation pressures were key parameters used to define the optimum ratio.

The suction process during installation posed several design challenges as the piles should be able to withstand the potential buckling effect as a result of this pressure. Several analyses were performed to assess the pile shell behavior while supported by surrounding soil and exposed to internal pressure. Once installed, the riser is connected and the pile is predominantly loaded by a vertical tensile force which is generated by the buoyancy tank at the top of the riser string. In addition, horizontal forces and bending moments are accounted for due to lateral displacement of the riser system, which follows water flow and FPSO drift. These drift loads can occur due to, for example, wave-current interaction and wind or storms.

Figure 2: Segments of the suction piles

A stiffened bulkhead was designed in order to transfer forces from the riser to the pile shell and surrounding soil. Fatigue was not a design driver for the foundation due to the layout of the rigid riser system. However, potential fatigue impact due to wave loading, vortex induced vibration, and other sources of fatigue loading were assessed to confirm this assumption.

Another important component of the suction piles is the corrosion protection system. This consists of coating of the top part of the suction pile, which remains above the mud line and sacrificial aluminium alloy anodes. Furthermore, the pile is equipped with several transport and installation aids in order to enable installation and perform survey activities.

Due to its installation depth of approximately 1.6 kilometers, all installation activities will be performed by a ROV. Installation equipment has been designed with additional redundancy in order to reduce any risk for lost time during the installation campaign.

The design of the suction piles is complete and the fabrication started in June 2014 at two different locations. Ten piles will be fabricated in Sharjah, United Arab Emirates, and the remaining eight piles will be fabricated in Porto Amboim, Angola. The installation of the piles is scheduled for the third quarter of 2016 and will be performed by Heerema's deep water construction vessel 'Balder'. ◄

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[1] *http://www.bluewater.com/fleet-operations/what-is-an-fpso/*

Figures:
Header, 1-2 Iv-Consult

Experiences from a KOers alumni
I graduated in 2008 after completing the Master track 'Structural Design'. Before graduating, I started working for Movares in Utrecht. As a structural engineer, I was involved in several projects related to the rail infrastructure in the Netherlands. This included the design of pedestrian bridges and train stations such as Rotterdam Central Station.

In 2011, I switched to Iv-Consult in Papendrecht looking for new experiences and opportunities. During the years that followed, I specialized in using steel as the main material for structures. At the same time, the variety of projects increased beyond what I had seen during my study at TU/e. For example, I worked on the design for several ship-to-shore container cranes for the new terminals on Maasvlakte 2. I have also been involved in offshore projects like 'Kaombo', as explained in the article above in more detail, being the biggest one. For Kaombo I traveled to different yards overseeing the fabrication process. This made me realize that a good structural design is based on much more than just code checks. Things such as easy access for welders, uniformity among connections and materials all benefit the quality of the final product.

As a structural engineer you will be involved in challenging design tasks. Each industry seems to have its own codes and standard practices to deal with items wsuch as fatigue, stability, or dynamic behavior of structures. However, once you have some understanding of the background, you will notice that the similarities outweigh the differences. If I may share a lesson of wisdom: Mechanical principles are the same all over the world. For you as structural engineer, this opens opportunities which are unavailable to others. So, once you have finished your study, don't focus on just the onshore building industry in the Netherlands while looking for job opportunities.

Caspar Breman
Specialist (RC), Iv-Consult.

Saving a monumental and ancient building from collapsing

Foundation repair of the Waag, Amsterdam

By: A.P. (Adri) Verhoef MSEng
Strackee BV Bouwadviesbureau

The Waag is one of the remaining 15th century port buildings in the city of Amsterdam. Previously, this stronghold was located in a moat, but after it lost its function, the area around the port developed into the current Nieuwmarkt.

In the past decades, recovery repeatedly took place at the Waag on the Nieuwmarkt in Amsterdam, often in combination with foundation work. Research, conducted in 1987, revealed that the northeastern and southeastern towers of the main gate were sagging, as indicated in *Figure 1*. The foundations of these towers were reinforced in 1988 by partial foundation repair.

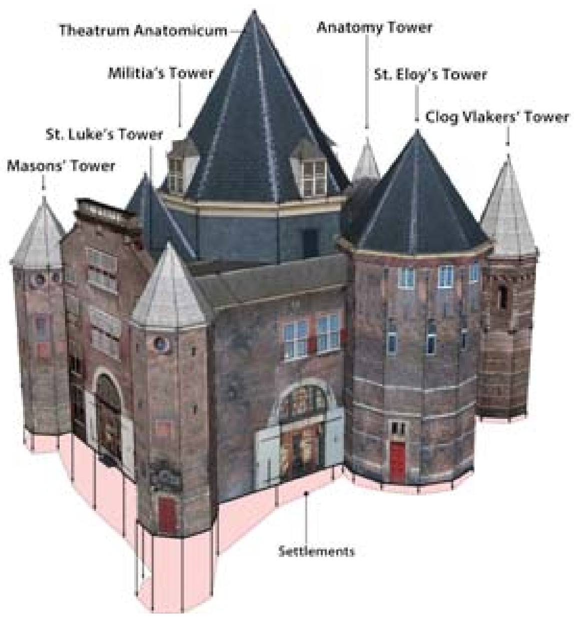

Figure 1: Differential settlements of the Waag

In 2009, cracks were again found in the northeastern tower, known as the Masons' Tower, which is one of the most vulnerable parts of the Waag. Immediately, temporary measures were taken by supporting and strutting the Masons' Tower, in order to prevent irreparable damage to the monument. Extensive research was conducted in 2011 and 2012 to find the exact cause of the cracks. The crack pattern indicated that the reinforced parts of the foundation sagged less than the adjoining parts without reinforcement. Besides the cracks in this tower, cracks also occurred in the northern part of the west facade, where the sagging increases annually.

In 2011, a workgroup did extensive research into the different possibilities for foundation repair. The chosen solution consisted of a combination of the 'table method' at the main gate and underpinning the walls at the front port. It was not possible to apply the same method everywhere, because the Waag has different foundation types.

Construction pit design

Excavation of the main and front gate

Historical research in the design phase proved the presence of a large number of monumental remains of foundations of the ancient city walls and an even older entrance bridge to the Waag. An inventory revealed many cables and pipes under the square. Thus, excavation under a slope would be risky and retaining walls with traditional sheet piles would simply not be possible. Therefore, a

Berliner wall was used as retaining structure, to be able to anticipate on the discovered obstacles in the ground. The possibility of using an open drainage proved this to be a suitable solution. Excavation research, prior to the recovery, showed an old facade opening below ground level at the backside of the Waag. This opening is used as a temporary construction access to the basement.

Observational method monitoring
In the design process, a phased excavation around the Waag was chosen, to be able to assess the influence of the excavation, based on present monitoring systems. The influence of the excavation remained thereby manageable. During the excavation it was found that the excavation of the deep-laid masonry foundation substantially reduced the negative adhesion, with a slightly upward settlement of the building as a result. Based on these findings, it was decided to carry out the excavation process accelerated and mirror symmetric, in order to maintain the horizontal equilibrium on the walls.

Water retaining culvert
Beneath the Waag, a water overpass is made using a monumental culvert between the Geldersekade and the Kloveniersbrugwal (*Figure 2)*. The culvert has a limited water permeability to the surroundings to prevent that the water level outside the culvert would be much higher or lower due to the drainage in the construction pit. Therefore, the drainage limits were determined. To prevent damage due to settlement and water pressure differences, a temporary steel support structure is placed with integrated work floor. The temporary work floor is used to assemble structural elements beneath the Waag, such as foundation piles and the necessary table structure. Despite the low free height of the culvert, material and equipment could be transported on a flat boat after drainage.

Structural design
The BMA (Bureau Monuments and Archaeology) expressed the desire to preserve the monumental masonry foundation by applying the foundation facilities as low as possible. Maintaining the existing basements was highly desirable as well. Therefore, a concrete table structure is the most suitable structure for the main gate. This method also offers the most flexibility in case of unforeseen changes in the foundation. Based on the maximum permissible excavation depth and the desired free height in the basement, the foundation plate thickness is limited by reinforcement with steel beams at the most crucial parts instead of traditional reinforcement. Some of the walls turned out to be more than two meters thick, these will be supported at both sides to prevent rotation and has a continuously underpinned concrete beam on the outside. In the existing situation, there was no basement space beneath the Masons' Tower, St. Luke's Tower, and St. Eloy's Tower. To still be able to make an integrated deep foundation plate, it is chosen to create a concrete floor on street level in advance, located at these towers. After that, the concrete foundation plate on basement level was installed. The foundation in the old and new situation is shown in *Figure 3*.

The existing alder piles were in bad condition; the piles had no arithmetic residual strength left, due to deterioration. To cope with the foundation of the main gate at this high risk level, the following measures were taken:

- Phased construction combined with real-time monitoring of the deflections of the building and the groundwater level in the direct surroundings of the construction site;
- The structure walls are supported by steel beams in drilled openings. In this way, the structure is placed directly on the new piles, which makes a jacked construction possible;

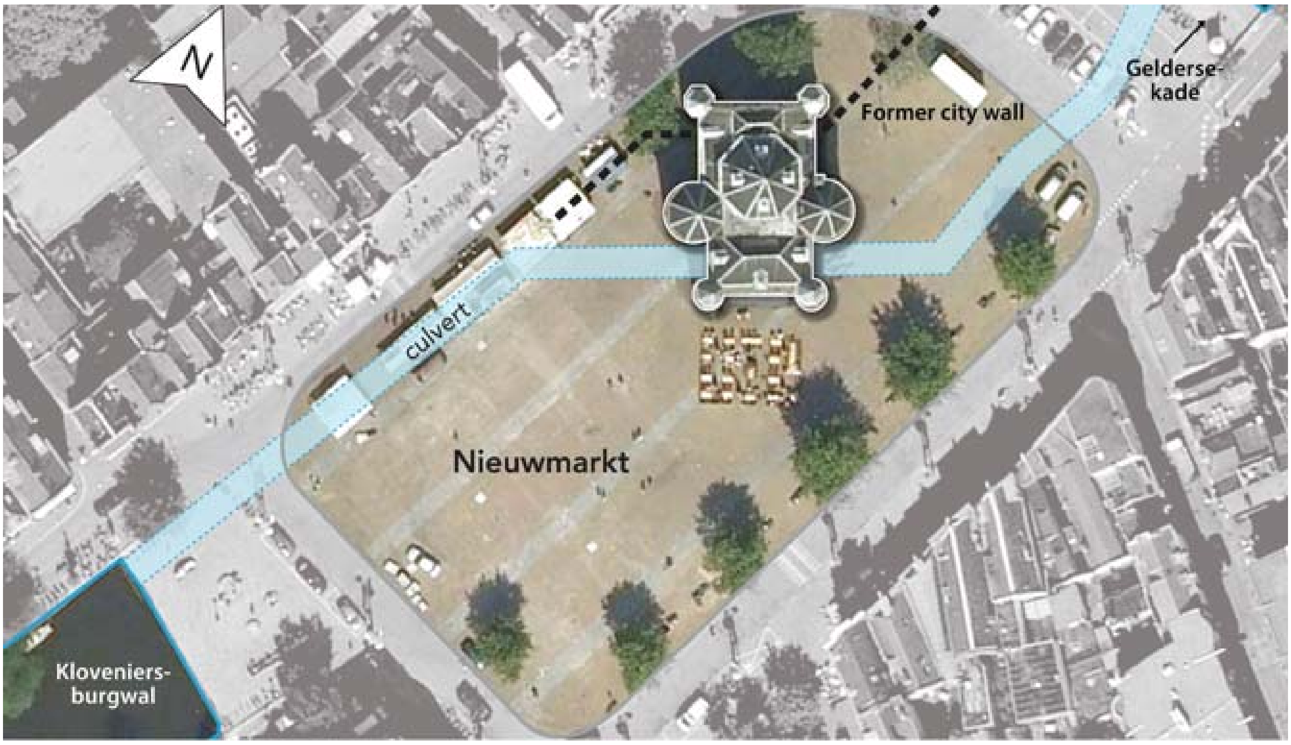

Figure 2: Location of the culvurt throughout the Waag and underneath the Nieuwmarkt

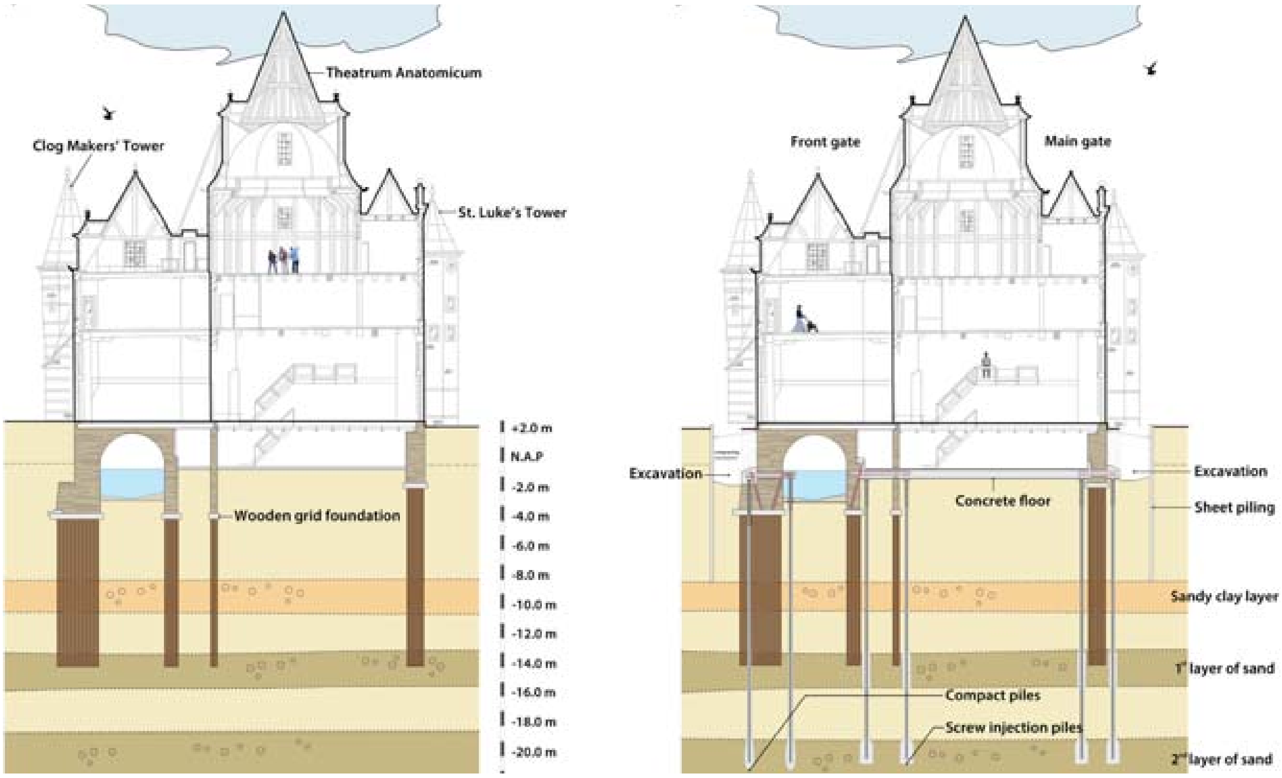

Figure 3: The old situation before (left), and new situation (right) after foundation repair

- Between the steel structure, in the notches and the piles, jacks are arranged to stress the piles in a number of steps and transfer the load from the old foundation directly to the new foundation. The jacked structure is readjustable in order to correct any residual settlements.

Front gate

The foundation of the main and front gate is separated by a brick overpass. The masonry foundation of the masonry arches are an integral part of the structure of the Waag. The construction level of the foundation of the overpass and the front gate are considerably deeper than the foundation of the main gate. These are not accessible without a drainage, for which a closed sheet pile structure is necessary. However, the environmental investigation showed that a closed sheet pile structure is practically impossible due to obstacles such as foundation residues, cables, conduits, etc. Therefore, a method is chosen in which a sheet pile structure is not needed. The piles will be drilled trough the existing foundation from a higher level, whereby the masonry foundation can still be completely supported. The piles under the existing walls are placed slanted, so that the new piles will be outside the existing grid foundation on foundation level (*Figure 4)*. In the preferred variant, a concrete foundation plate with vertical piles is chosen at the location of these two towers. In this way, there is no need to drill through the likely poor conditioned thin masonry and the new piles are free from the grid foundation. The foundation of the two towers will be connected by a concrete plate that functions as a tension rod. This concrete plate is also linked to all piles that are drilled directly under the south facade of the Waag. In this manner, the force introduction will also be ensured in case of any failing quality of the masonry, and the horizontal forces are equalized. This chosen detailing upgraded the reference period for the piles beneath the wall to at least 100 years.

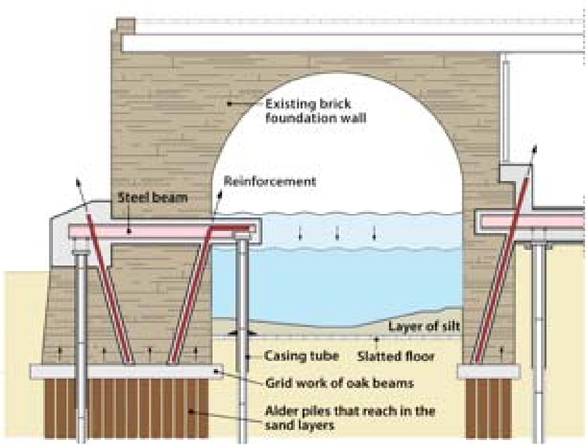

Figure 4: Foundation repair around the culvert

Monitoring system Stabi-Alert

To be able to monitor the deflections of the structure during repair work, a system is used called Stabi-Alert; a system that can detect rotations up to 0.0001 degrees. The measured angular displacements are coupled to a wire model so that the deformations could also be quantified. Based on the data set before the construction work, alarming and limit values are established, which were monitored real-time during construction.

Pile choice

A vibration-free pile system was chosen. For the main gate, screw injection piles are used. For the piles of the culvert, that go through the existing masonry and grid foundation, it is important that the drill diameter remains limited.

Therefore, VHP/WCP (screw injection piles/compact piles) piles are chosen, whereby a concrete body is formed in the load bearing layer under high pressure. Extra pipe sleeves are used to realize a guaranteed grout casing until the top of the pile.

The heavy constructed fenced walls of the Waag are extremely sensitive to differences in settlement in the plane of the walls. To prevent damage caused by differential settlement, parts of the building are stressed with small repetitive jack steps; *Figure 5* shows the jacking system. During jacking, real-time monitoring verified that the deformations that occurred remained within the predetermined limits. The jack steps and the limit values were based on compression tests, carried out before the restoration on a representative location of the Nieuwmarkt.

Dilations

Connecting foundations

In order to prevent damage initiated by settlement in the future, other types of foundations should be separated from the new foundation. This mainly concerns the foundation of the, on two sides connected, old city wall and the partial foundation repair constructed in 1989. The concrete beam, resulting from the foundation repair, will be removed. By dilating the partial repair, using an accurately engineered plan, it is guaranteed that the structure was first completely relieved by stressing the new foundation. After that, the partial repair structure is removed in segments to prevent settlements afterwards.

Figure 5: Jacking system between steel beams and the piles

Culvert

Differential settlements will occur in the future between the culvert, founded on the first sand layer, and the new foundation on the second sand layer. To prevent damage due to these settlements, a plan is made to entirely dilate the culvert at two places. These dilations are filled with water retaining gel, which is so elastic that it can take the deformations between the part of the culvert that is founded on the old foundation and the part that is captured with the foundation repair. ◄

Figures:

Header, 1-5 Strackee BV Bouwadviesbureau & E. Oort, PMB Amsterdam

ENCI-Multiple Day Excursion 2016

Munich and Stuttgart

By: Sander Montrée
Chairman ENCI-MDE committee

The ENCI-Multiple Day Excursion (or ENCI-MDE) is one of the annual activities organised by study association KOers. This year, a group of sixteen students set out for Germany, where the cities Munich and Stuttgart were visited.

It all began on a cold Thursday-morning in February. Sixteen barely awake students got on two buses, ready for a whopping 700 kilometer drive. After singing for birthday-boy Wessel, we traded the university for the highway.

Many hours, a missed rendez-vous at a gas-station, and 500 kilometers later, we found ourselves in Stuttgart, where a tour through the Mercedes-Benz Museum was planned. Arnold Walz, who was part of the team responsible for the design of the building, guided us through the building explaining design choices, execution problems, and challenges within the structural and architectural model.

Figure 1: Diner at the Augustiner Bräustuben with the student council

After the tour, we drove the remaining kilometers to Munich, checked in at our hostel and walked to the Augustiner Bräustuben. At this traditional Bavarian restaurant, we met a group of students of the Student Council of the University of Technology of Munich (TUM). The Student Council helped us to arrange excursions in Munich, so we were very pleased to meet them.

We discussed the differences between the German and Dutch education system, our plans for the trip, and of course the student life in Munich and Eindhoven. After a tasty diner, we were given a brief tour around the campus of the TUM by night and ended up in one of the bars recommended by the students.

Friday started with a visit to the construction site of a former weapons depot, which is being renovated to be part of the Munich University (*Figure 2*). Here, a tour was provided by Heike Neudecker (engineer), Matthias

Figure 2: Group photo at the construction site of Heidelberg Cement

Pauly (architect from Staab Architekten), and Dr Robert Lukas (concrete supplier from Heidelberg Cement). After seeing everything, from the basement to the entrance and from the concrete test cubes to the entire concrete administration, we left the construction site to visit another car-related building: BMW Welt.

First, a presentation was given by SFF Ingeneure AG, at their office, about the design and realization of the structure. Then we traveled to BMW Welt to admire the structure in real life. Everyone was impressed by the double curved double cone shape (representing a tornado) and the giant spans (over 100 meters) that are all serving the experience and perception of BMW.

Figure 3: BMW Welt

Besides the magnificent structure of the building, many students were tempted by the cars and motors on display. After our visit to BMW Welt, we walked to the other side of the highway to visit the Olympiapark, the scene of the 1972 Olympic Games. The Olympic Stadium, designed by Frei Otto, has a lightweight roof spanning over half of the seats of the stadium. After a walk around the stadium, we headed back to our hostel to prepare for the evening, which consisted of diner in the Ratskeller and some drinks at the Münchner Freiheit (the Stratumseind of Munich). The rest of the evening contained a lot of embarrassing dancing and singing and lasted until the early hours of Saturday.

Figure 4: The Olympic Stadion

This year, we decided not to have a Crazy 88, a picture-hunt or a question-route, or did we? This year, we combined multiple principles into an entertaining tour with the name: 'die Verrückte Städtereise'; a tour around the city, visiting the cultural, architectural, and structural highlights of Munich. The tour included the Allianz Arena, the central station, the Frauenkirche, the City hall, the Hypo-Haus, the Highlight Towers, and many more interesting sites.

During the tour, students had to answer questions to find the right route, make creative pictures in the city and find the hidden KOers-stickers, spread by committee member Lieneke in an earlier visit. The pictures were to be judged by the organizing committee and the group with the best pictures would win 'die Verrückte Städtereise'. At the moment of writing this article, the committee has evaluated the pictures and determined a winning team, congratulations to Gosse, Eline, Renée, Wessel, and Sander!

Unfortunately, the weather did not agree with our plans for the city trip and the rain caused us to reexamine the plans for the evening. Together with the participants, we went for yet another joint diner in a fairly new Italian restaurant close to the hostel and finished the day with some drinks and playing some pool in the bar of the hostel.

Figure 5: The winning team of 'die Verrückte Städtereise' at the Siegestor

The final day of our ENCI-MDE was all about the trip back to Eindhoven. Just as on Thursday, we visited Stuttgart again, this time to visit the Killesbergturm; a sightseeing tower on a hill in Stuttgart. The tower, a lightweight structure swaying quite vigorously in the wind, was a nice final excursion of the trip.

The last kilometers to the Netherlands were filled with singing along to the radio (the music definitely improved compared to Thursday) and catching up on some missed and very welcome hours of sleep.

On behalf of the committee, I would like to thank the participating students for their enthusiasm and efforts during the trip. I would also like to thank all the companies that welcomed us in Munich and Stuttgart and. A special thanks goes out to the students of the student council of the TUM, who helped us arrange visits in Munich and accompanied us. Finally I would like to thank the rest of my committee: Lars van den Bulck, Arno Poels, and Lieneke van der Molen for organizing this trip.

Ich heb ab! ◀

Rozet, Arnhem
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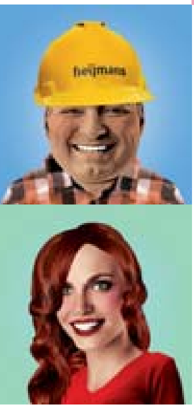
Bastionder, Den Bosch
Van Roosmalen Van Gessel



The world record is back in Eindhoven!

Beer Crate Bridge 2016

By: Niels Bartels, Coert Doomen & Gosse Slager
Beer Crate Bridge committee, Structural Design group

In September 2015, the Beer Crate Bridge committee, consisting of eighteen students, started with one goal: taking back the world record to Eindhoven! The record is given to those who create the largest span using beer crates. It is not allowed to use any connectors or fasteners between the crates and the bridge should exist of either empty crates, crates with empty bottles or crates with filled bottles. This edition of the Beer Crate Bridge had an extra challenge, namely, building the bridge over water. Besides that, the design of the bridge of 2012 was optimized.

Since 2004, several bridges of beer crates were built. A short summary of the records and attempts is given below:

- 7.40 meters by TU Delft in 2004;
- 7.60 meters by University of Twente in 2005;
- 12.60 meters by TU Eindhoven in 2005. This was the first attempt done in Eindhoven;
- Unsuccessful attempt by University of Twente in 2010;
- 15.60 meters by TU Delft in 2011;
- 19.55 meters by TU Eindhoven in 2012. In this year, a new design was made, in which the crates were rotated 90 degrees to form an arch;
- Unsuccessful attempt by TU Delft in 2014;
- 22.15 meters by TU Delft in 2015.

And now, in 2016, TU Eindhoven made the first bridge of beer crates over water, with a span of 26.69 meters! With this bridge, the world record is back in Eindhoven.

Structural design

At first sight, it looks simple to construct a bridge out of beer crates. However, lots of structural principles, research, and improvements are needed to actually build a beer crate bridge without the use of any connectors or fasteners.

The most typical material property of beer crates is their inability to transfer tension forces, comparable to dry-stacked stones as stuctural material. For this reason, the basic principle of the beer crate bridge is based on an arch structure, initiated by Eindhoven in 2012. Empty crates are used in the arch itself to reduce the weight. The crates are placed following the principle of an inverted catenary line. The horizontal reaction forces are resisted by two towers of crates with bottles filled with water.

Stones in an arch structure are ideally shaped in such a way that the sides are perpendicular to the line of thrust. If this is the case, the structural elements are fully loaded in compression. However, beer crates have a fixed rectangular shape, which results in both compression and shear forces at the vertical intersections. The capacity of the crates for both compression and shear was tested in the laboratory *(Figure 1)*, which was one of the first stages in the design phase. An interesting result was the maximum capacity in compression before plastic deformation of 40 kN, which is equal to about four cars. The shear force capacity was tested by 90 degrees tilted prestressed crates, after which the middle crate was pushed perpendicular to the tilted setup. These tests showed that the creates are relatively strong and will not collapse individually in the bridge.

The global forces in both the arch and the supports were determined by the line of thrust, equal to an inverted chain line. This line of thrust is constructed by the graphic statics method, which takes both the dead weight of the crates and the shape of the catenary line into account. The graphic statics method and definition of the catenary line were implemented into a parametric Grasshopper model. The advantage of this implementation was a fast generation of initial designs with a direct result of the corresponding reaction forces.

Figure 1: Testing the shear force resistance of the crates

The generation of various designs was needed to choose the most suitable catenary line, for which our stated boundary conditions were fulfilled the most. These boundary conditions followed from an analysis of the constructed bridges in 2012 (Eindhoven) and 2014 (Delft). Some problems occurred during the construction of these bridges, which we tried to prevent this year. One of these problems was that crates fell out from the bottom in 2012. The biggest problem in 2014 was the way the scaffolding was removed, which resulted in an asymmetric shape of the arch. Another improvement compared to 2012, 2014, and 2015 could be made by another way of stacking, excluding the presence of continuous lines over sections.

Figure 2: The test bridge with a span of ten meters

One of the most critical parts for an arch structure in compression is the way the forces are applied to the structure. It would be ideal if the scaffolding is removed in a split second, but this is practically not possible. For that reason, the scaffolding is removed by parts from the middle towards the sides in a symmetric way. At a certain point, this results in a situation where a part of the arch is stressed, resulting into horizontal reaction forces. For this reason, the corners between the towers and the arch itself are filled with crates to transfer these horizontal forces during construction. This is one of the issues that was not initially taken into account in the designs of 2012 and 2014.

Another point of attention is the way of horizontal jacking the complete bridge from the side. The goal of horizontal jacking is to fully interlock the crates, without actually bringing any prestress in the bridge. This is in contrast to the idea in 2012, where the goal was to use the jacking to add prestress in the arch, which would result in getting the bridge loose of the scaffolding. However, this resulted in a relatively flat line of thrust within the section, which changed to a more curved compression line due to deformation under self-weight. This turnover in line of thrust was discovered during a test set up in the laboratory (*Figure 2*), and a simplified simulation of the jacking by a finite element model in Abaqus, shown in *Figure 3*.

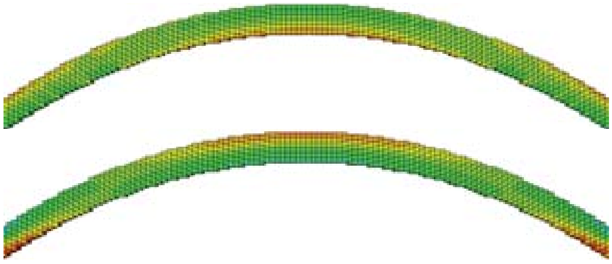


Figure 3: Results of the model in Abaqus. Top: dead load only, bottom: deadload with horizontal jacking, red shows the lowest pressure in the arch

A typical aspect of this year's design were the effects resulting from building over the water. We were told that the soil directly at the sides of the Dommel could be weak. For this reason, we contacted one of our partners, Bartels Ingenieurs, to discuss our plans. One of the conclusions was the decision to prestress the soil for a couple of weeks by weights, although the engineer of Bartels did not expect any difficulties. In the end, he was right and the foundations did not show large settlements.

Daily reports

01/04 - 15/04: Foundation

On Friday April 1, the activities for the foundation of the Beer Crate Bridge started. The foundation of the Beer Crate Bridge required a horizontal level. Since the embankment of the Dommel has a large slope, sand was needed to make this level horizontal. To prevent sand from sliding, Legioblocks were put on the embankment. On April 4, the container, made from the Legio Blocks, was filled with sand. Afterwards, Stelconplates were put on the sand to provide a strong foundation. To prevent the embankment from settling during the construction phase, a preload, created with extra Stelcon plates, was applied to the foundation two weeks before starting constructing the bridge. On April 15, three HE1000B beams were placed: two for supporting the scaffolding and one to serve as a walkway between the embankments of the Dommel.

18/04: Placing the scaffolding

This day started with building the scaffolding on the HE1000B beams. In the afternoon, the first of four trucks arrived with the beer crates. At the end of the day, all beer crates were unloaded from the trucks. The first part of the jacking structure was also built on this day. Steel beams that prevent the jack from moving during jacking were placed on the Stelcon plates.

Figure 4: Bridge under construction

19/04: Building the first tower
The day started with building the first half of the tower out of beer crates filled with bottles of water. After the tower was at a height of 3.5 meters, a start was made with the arch of the bridge. The first 5 of the 121 sections of the arch were built. The prefabrication of the middle sections of the arch was started as well.

20/04: Building the first part of the arch
On the third day of building, the arch was almost built to the top. Up to the 20th section, all sections are built on the scaffolding by hand. From section 21, the sections are prefabricated with tension belts and placed in the arch as whole sections. Besides building the arch, many measurements took place to ensure the bridge had limited deviations.

21/04: Building the second part of the arch
On this day, work activities started from section 54. Besides building the arch, many side activities took place on the building site. Benches, letters, and small bridges were constructed from beer crates. At the end of this day, the arch was finished.

22/04: Building the second tower
In the morning, the second tower on the other side of the Dommel was built. In the meantime, the jacking structure was placed on the steel beams that were placed on Monday. After placing and testing the jacks, the first tower was moved 8 centimeters by the jacks. After the displacement was introduced, the tower was finished and the jack was pushed back.

23/04: D-day
This day, the plateaus of the scaffolding that supported the arch were lowered. Lowering the thirteen plateaus had to be done from the middle towards the outside and symmetric. The process of lowering the plateaus took around four hours and started at 10:30 h. Around 14:45 h, the bridge was free from its temporary support and the record attempt was started. Due to the strong wind, the first attempt was aborted after ten minutes; a horizontal out-of-plane support, that was placed on the top of the arch and prevented the bridge from moving any further was touched, which meant that the bridge was laterally supported for a moment. Around 15:30 h, a second record attempt was started, and with success! After one hour, the beer crate bridge was still standing. The world record was from that moment on back in Eindhoven with a free span of 26.69 meters!

Figure 5: The scaffolding is moved away and the span has a free view

Acknowledgements
On behalf of the Beer Crate Committee, we would like to thank the following partners who helped to get the world record of the Beer Crate Bridge back to Eindhoven: Dream & Dare Festival, Bartels Ingenieurs, Eindhoven Studentenstad, and Universiteitsfonds Eindhoven for financial support. A. Jansen, M. Heezen, Safe, Collé, Bavaria, Huybregts Relou, Van Elst, Van der Winkel, Hilti, Aarts, Manders Licht & Geluid, and Hakron for equipments, materials, and man hours. We would also like to thank the volunteers who helped us with constructing the bridge. And last but not least, many thanks to the staff of the Pieter van Musschenbroek laboratory for the experimental research and for designing and constructing the jacking structure and all other partners who helped us and are not mentioned above. ◀

Figures:

Header, 4, 5	*Paul Hemmen*
1, 3	*Beer Crate Committee*
2	*Eric Wijen*

KOers abroad

Studying in Sydney, Australia

By: Dion Goris
KOers member and Structural Design student

G'day mates! My name is Dion Goris. I am a second year master student at the unit Structural Design (SD). As a temporary citizen of the beautiful city of Sydney, I was asked to write about the decisions I made in order to get here and my experiences so far. Currently, I am participating in an exchange program between the University of Technology Sydney (UTS) and Eindhoven University of Technology (TU/e) in the period of March until the start of June.

Going abroad is not a decision you make in one day. I got really enthusiastic two years ago, after hearing the great stories from two of my high school friends, who studied in Bangkok and Adelaide. Also, I always wanted to participate in extracurricular activities that would broaden my horizon and would make me stand out when applying for a job.

Figure 1: Dion in front a faculty building of the UTS

In search of information, I visited the International Exchange Coordinator Henny Houben at TU/e. During the process, she assisted me in the best way possible. She provided me with a list of all the universities in the world that have an exchange program with the TU/e. The great advantage of such a program is that you do not have to pay tuition fees to the partner university. Choosing the right university was difficult at first. I started out making a list of universities that use English as their main language and support courses for structural and civil engineers. Apart from academic purposes, I wanted to use this journey to learn more about myself as well. Altogether I decided to apply for UTS.

The application process consists of multiple steps and takes a fair bit of time. You have to meet the requirements of both universities (including: 180 ECTS, proof of sufficient level of English, and a letter of recommendation by a professor). Another part of the application is choosing your subjects. As I do not want to miss out on any of the important courses at TU/e, I decided to add my UTS courses on top of the 15 ECTS we have to fill in the 'free space' of the SD master. The courses I chose at the faculty of Engineering and Information Technology treat topics I have not studied before, namely: 'Computer Modeling for Structural Engineers', 'Facade Engineering', and 'Site Establishment and Management'.

Figure 2: With friends on a trip to Canberra and Kosciusko National Park

I experienced a big difference in teaching styles between the two universities. In UTS, the professors use a lot more assignments, tutorials, computer labs, and discussions on top of the normal lectures. This forces you to study each week. On the other hand I must admit that the courses seem easier than at the TU/e, which leaves me with plenty of time to discover Australia itself!

Figure 3: The seashore Wineglass bay in Tasmania

As I wrote earlier: an exchange is not only a great educational experience, but also one of the biggest opportunities to learn more about yourself. I have never traveled by myself before and I was a bit nervous at first, but now, two months later, I have met dozens of new friends and visited a lot of the most beautiful places on earth (inluding Tasmania, the Great Barrier Reef, tons of National Parks, breathtaking beaches, and a lot more to come).

Here are some pointers I would like to give when you are considering to go abroad: start in time, be aware of a possible culture shock, create insight in your earnings and expenses in advance, and use the housing opportunities provided by the university. Are you considering to go abroad? My advice: do not hesitate, just DO IT! It will help you grow, both professionally and personally. I am enjoying every single minute and I will make the most out of my remaining time here. Cheers mates! ◄

Master's thesis

Behavior of Azobé (Lophira Alata) in compression perpendicular to grain

By: G.H.J. (Gydo) Fransen MSc
Supervisors: Prof.dr.ir. A.J.M. (André) Jorissen, dr.ir. A.J.M. (Ad) Leijten, ir. W. (Wouter) Liem

The performance of the design rules for compression perpendicular to grain in the current Eurocode 5 (EN 1995-1-1+A1 2011 [1]) is currently up for discussion within the Eurocode 5 committee. In addition, it is unclear if the design rules, which are developed based on softwood data and have an empirical background, provide accurate predictions of the compression strength perpendicular to grain of hardwood. Therefore, the graduation research aims to provide insight in the behavior of the widely applied hardwood species Azobé and compares the performance of various models for compression perpendicular to grain that are currently available with the performance of the design rules in the current Eurocode 5 [1]. Furthermore, based on the outcomes of experiments, numerical research is conducted to investigate the rolling shear failure mechanism, since this mechanism seems not to be accounted for by any of the models regarded. In the following, only the numerical material model is discussed.

Azobé is applied on a relatively large scale in civil and marine works such as bridges, lock gates, and fenders in the Netherlands and abroad because of its favourable strength and stiffness properties and its exceptional durability. Alongside, the material finds application as filler and load spreading material, for instance in dry docks or in heavy lift applications, because of its ability to deform and to alleviate peak stresses on the substructure.

Observations

In compression perpendicular to grain tests performed on Azobé by Slager and Vermeulen [3], rolling shear is often observed in slender beams, especially in those configurations where the load is applied near the beam ends (*Figure 1*). On the contrary, numerical models that have reviewed compression perpendicular to the grain in timber in the past, do not consider the rolling shear failure mechanism. For this reason, since this mechanism can lead to an overestimation of the strength by the models currently available, numerical analyses are carried out to the occurrence of rolling shear failure in hardwood. Hereby, it is intended to investigate the occurrence of rolling shear failure and its influence on the strength by adopting an engineering approach.

It is observed in the specimens used by Slager and Vermeulen [3] that cracks initiate almost exclusively along growth rings, *Figure 2*. Although these growth rings, like in many hardwoods, are not always clearly visible and seem absent in Azobé, their orientation can often be derived from the presence of drying cracks, whose orientation is always perpendicular to the growth rings. Additionally, it is noticed that for lying or standing growth ring orientations (radial and tangential direction, respectively) no severe cracks appear within the displacement range investigated. Apparently, the presence of severe cracks can be ascribed to a shear failure mechanism. In the end, three distinctive stress-strain diagrams are observed, of which the typical shape is shown in *Figure* 3. Clearly visible is the dependency of the load-slip curves on the growth ring orientation.

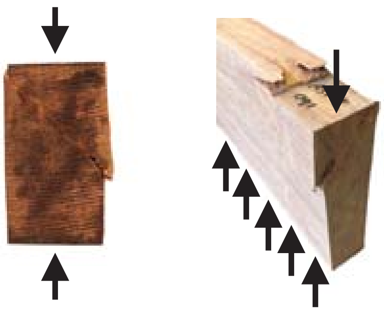


Figure 1: Rolling shear

Figure 2: Cracks (white dotted lines) follow the growth ring pattern

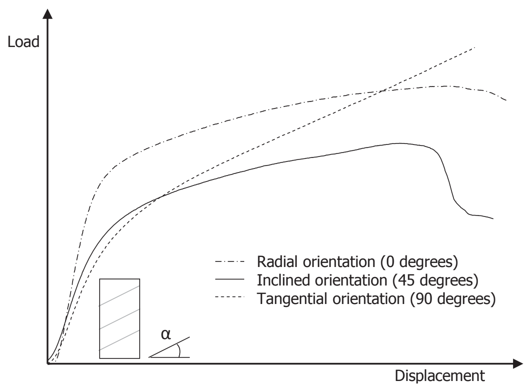


Figure 3: Typical stress-strain curves

Geometry

A two-dimensional cross-section of 95x45 mm^2 (depth, width) is created in the radial-tangential plane, as depicted by *Figure 4*. The reason for this particular orientation is that rolling shear is observed to initiate and develop in this plane during standard strength tests, which are based on EN 408 [2]. In the standard strength tests, a small specimen

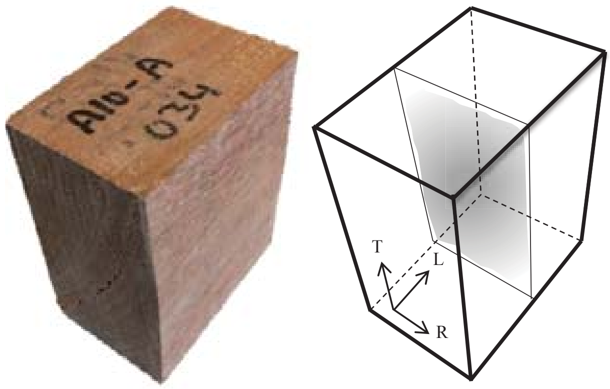


Figure 4: EN 408 [2] specimen (left), RT plane (right)

is uniformly loaded by a steel plate over the full top and bottom surface area. Next, add the fact that the specimen has relatively small dimensions, and it may be assumed that the material behaves uniform over its length (L). Therefore, validation of a two-dimensional model is possible with the three-dimensional experimental results.

Material model

As a simplification of the complex behavior of wood, the Hill yield criterion is applied in combination with a constitutive hardening law to describe the material behavior in compression and tension parallel and perpendicular to grain. However, with this model it is not possible to describe failure in tension and shear and subsequent softening of the material properties. Namely, the elastic-plastic constitutive hardening law is only able to describe yielding of the material. In order to enable softening due to tension or shear failure, discrete fracture planes that match with the growth rings are introduced into the model. In these planes, two fracture modes, being tension perpendicular to the grain (mode I, in the RT plane), and rolling shear (mode II, in the TR plane), are enabled in the fracture planes. Subsequently, a linear traction-separation response is chosen to represent the fracture. Herein, the fracture strength, cohesive stiffness, and post-failure behavior are represented. In addition, friction is modeled in case of shear. This is done by introduction of a Coulomb-friction law, which becomes active once the fracture strength is reached. In that case, the shear-slip behavior is described by the envelope of the shear-slip (is traction-separation, but then for shear) diagram for shear fracture and for friction.

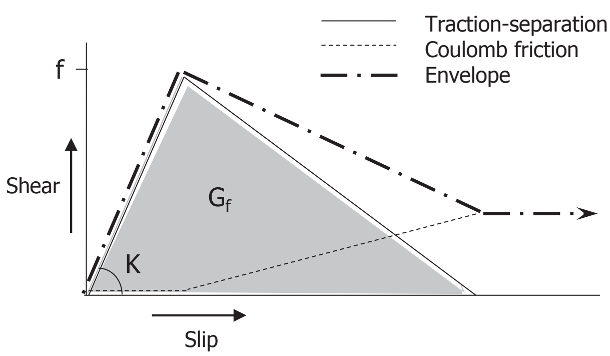


Figure 5: Schematic representation of the shear-slip law with linear softening in combination with friction

The intended behavior of the material model with discrete fracture layers is described in *Figure 6*: the black blocks represent the bulk material (governed by the Hill criterion and a hardening law), while the white block represents the fracture plane (governed by the traction-separation law), which in *Figure 6* has been given a thickness to clarify its behavior; in the model, it has no thickness. Due to a high cohesive stiffness K, deformation of the cohesive zone will be negligible once the fracture strength is reached; namely, the bulk material is able to deform and develop plasticity before the final fracture strength of the cohesive layer is reached.

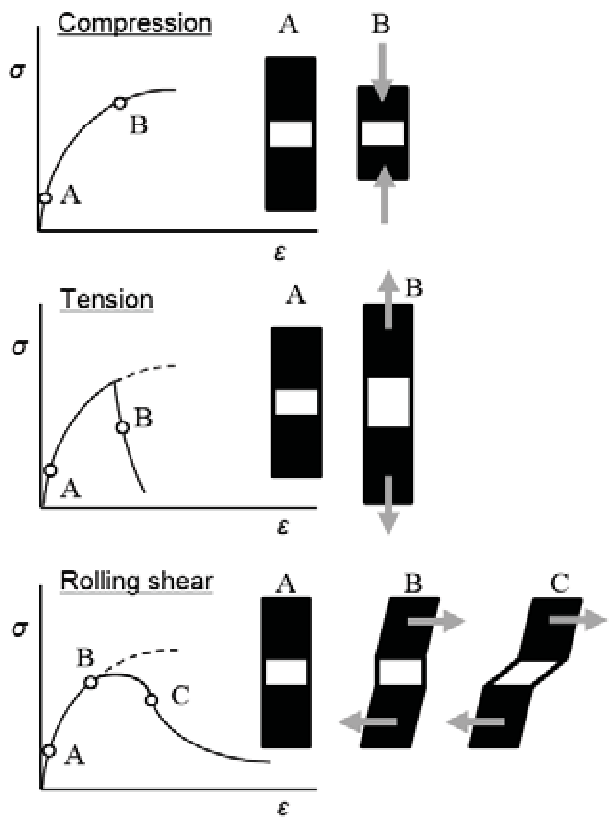


Figure 6: Material behavior. Dotted line shows behavior without softening and friction

Finally, the anisotropy in the hardwood material, which is assumed to be orthotropic in the model, is handled by the introduction of so-called (in Abaqus [4]) potentials. These potentials, or R-values, vertically scale the single hardening function that can be entered in Abaqus [4]. For the 22-direction and 12-direction, the potentials are given a value such that the general shape of the load-displacement diagram matches with the experimental results (*Figure* 7).

FE model

A sufficient number of discrete fracture planes is introduced to assure that the location of these planes does not have an influence on the results. Subsequently, a regular mesh, consisting of reduced-integrated first-order continuum elements, is created in the region of interest using a support grid (*Figure 8)*. This type of element is chosen based on the behavior of the material, which includes contact in the discrete fracture planes, plasticity, and large deformations.

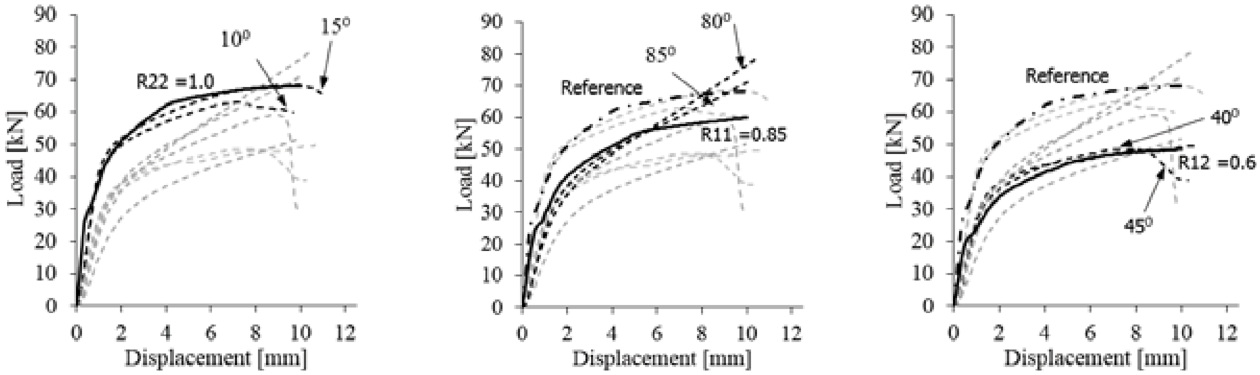


Figure 7: Orthotropy is handled by so-called potentials (R-values). Radial ring orientation with R22=1.0 is used as reference

The numerical model, which includes elastic-plastic bulk material and discrete fracture planes, can only predict correct behavior for the experiments where the first crack initiates along a weak growth ring. Therefore, in the numerical analysis the focus is on inclined ring orientations of 45, 60, and 75 degrees.

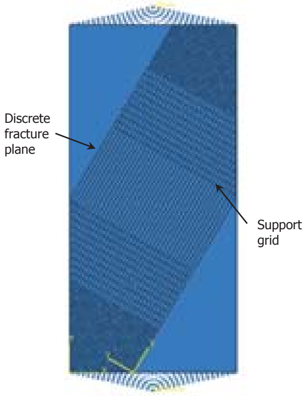


Figure 8: Discrete fracture planes, support grid, and resulting mesh for 60⁰ growth ring orientation

Results

Of all simulation results, only one is shown in *Figure 9*. It shows the influence of the fracture strength f_{II} (9 - 12 MPa) and fracture energy $G_{f,II}$ on the load-displacement behavior for a growth ring orientation of 45 degrees. The dotted grey curves in the graph are the experimental results.

Conclusions

Although a clear growth ring pattern seems to be absent in Azobé, it is observed in experiments that, for inclined orientations, cracks initiate solely along weak planes parallel to the growth rings. A parameter study is performed for three fracture parameters, being mode II fracture energy, mode II fracture strength, and friction. From pre-analysis, it was already determined that, for the growth ring orientations investigated, mode I fracture parameters (tension perpendicular to the fracture planes) do not affect the load-displacement behavior. From the parameter study it can be concluded that:

- The growth ring orientation is the main parameter that influences the load-displacement curve up to the crack initiation load;
- The crack initiation load is determined solely by the fracture parameters fracture strength, fracture energy, and friction;
- The fracture parameters fracture strength, fracture energy, and friction seem to have no influence on the location of crack initiation. Therefore, indirectly, since moisture content, level of grain interlocking, and presence of ray tissue might affect these fracture parameters, it may be concluded that these have no influence on the location of fracture initiation either;
- As the numerical model excludes local defects and comprises perfectly straight growth rings, the location in the specimen at which fracture initiates seems only to be determined by the growth ring orientation. ◀

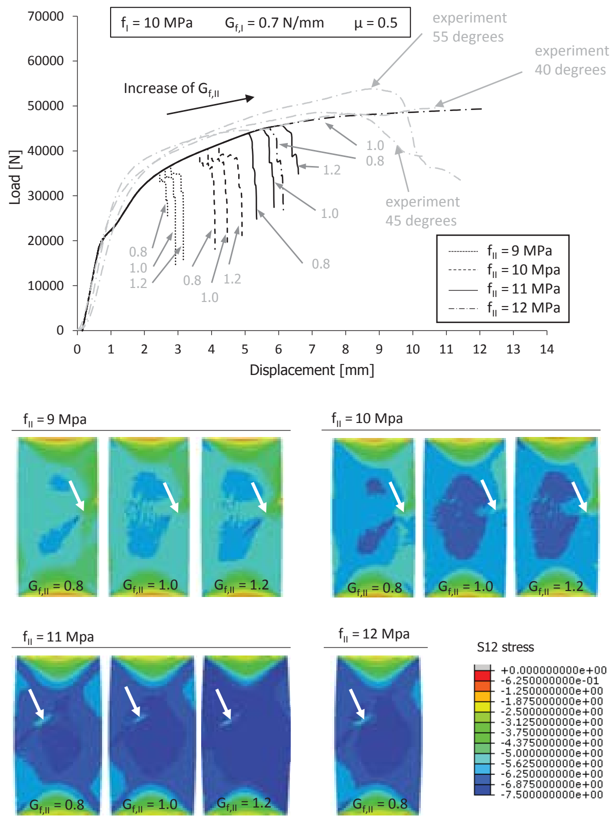


Figure 9: Simulation results, 45 degrees growth ring orientation

References:

[1] EN 1995-1-1 (2011), Eurocode 5: Design of timber structures A1, Brussels: CEN, 2008.
[2] EN 408 (2012), Timber structures - Structural timber and glued laminated timber - Determination of some physical and mechanical properties.
[3] Slager, G.J., Vermeulen, G.A. (2015), Compression strength perpendicular to the grain of hardwood, Eindhoven University of Technology.
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KOers Education Update

By: Lieneke van der Molen
Commissioner Education 46th board KOers

This edition of the KOersief also includes a KOers Education Update. Apart from exam results, this section discusses new items, important matters or interesting projects within the master Structural Design.

Bio-Based composite pedestrian bridge
This project started in February 2016, as part of the Lighthouse Projects 2016 by the 3TU Federation. The aim of the project is to bring the applications of fully bio-based materials, in the built environment, a step further by exploring the options for a bio-based pedestrian bridge. This bridge should have a span of 14 meters and 1.5 meters width.

A design workshop has already taken place, in which seven alternative designs were created. In the second design workshop, the seven designs are elaborated. At the end of the workshop, one or two design options remain. Eventually, the bridge will be constructed and positioned over the stream the Dommel, near the Auditorium. A conceptual design of the bridge is shown in *Figure 1*. Three students work on this master research project. They investigate the dimensioning and optimization of the design and perform material experiments.

For this project, TU/e collaborates with: TU Delft, NPSP BV, CoE BBE, and the SIA RAAK project 'Biocomposieten voor bouwkundige en civiele toepassingen'.

Figure 1: Conceptual design of the pedestrian bridge

Updates Graduate School

- One of the basic elements of Graduate School is having courses of 5 ECTS, which resulted in merging or upgrading the previous courses. At this very moment, the master Structural Design still has five electives of 2.5 ECTS, namely:
  - Geotechnics and Soil Mechanics (7KT5M0);
  - Seismic Structural Design (7KT6M0);
  - Finite Element Method, non-linear (7KT7M0);
  - Masonry Structures (7KT4M0);
  - Adaptivity and Technology Transfer (7KT3M0).

  Upcoming academic year, the courses 7KT5M0 and 7KT6M0 will be merged into one 5 ECTS elective. The other three courses remain 2.5 ECTS electives;
- A new elective of 15 ECTS makes it possible to do an internship at a company or a combination of courses abroad. You must discuss details towards completion of this elective with your coach. It is possible to follow courses at another Dutch university. It is also possible to relate this course to your graduation project. Once you choose to do this, the course becomes an upgrade of your graduation project instead of an elective in your master;
- Upcoming academic year, a new 5 ECTS project will be launched by the name: 'Design and construction of an Innovative Structural Design'. In this project, students obtain knowledge and skills in the field of Innovative Structural Design with unconventional materials and typologies. The course code is yet to be decided;
- Each student must compose a study program for his/her master, which must be approved by the exam committee. Your coach can apply your program at the exam committee for you. If this is done in an early stage, it is possible to adjust the program to certain requirements. For example: if a student has certain ideas about his/her graduation project in an early stage, the program can be adjusted to this. Then your coach can direct you to a potential supervisor sooner. This is beneficial and thus advisable.

Graduation project studios
Some projects within the master of Structural Design are held in studios. There are two types of studios: horizontal studios and vertical studios. The graduation project studios within the chair of Innovative Structural Design (ISD) are vertical studios. This means that a student can step in the project studio whenever he or she likes, with an individual schedule. The chair of Steel Structures has horizontal studios for the graduation projects; a group of students simultaniously start and finish working on a project with a related topic. However, practice learned that the students did not finish simultaniously.

The main reason for creating these studios is to allow students to learn from each other. A studio stimulates them to work together and to find solutions to certain questions or problems, which eventually makes them less dependent of project meetings.

Currently, there are two graduation studios at the chair of ISD: one for adaptive structures and one with the focus on structural optimization. The subjects of the projects vary enormously, yet they are connected to each other within the theme of the studio. It is possible to do both research and design, separately or combined. Within this studio, you are free to suggest ideas towards your own project. In an early stage, a student can ask his or her fellow students, who are further in their project, certain questions to obtain their help. Later on, they will fulfill this function themselves. Project meetings are held with the full studio, but when desired, individual meetings can also be planned in addition to the general meetings.

The studio of Steel Structures was different. The research projects done by the graduation students were linked to the work of PhD-student Rianne Dekker. An important matter in the horizontal studio is that each student runs the same process, but with different topics. This makes meetings more efficient as students learn from the feedback given by the supervisor to fellow students and it allows the students to support each other in different stages, as each has a different skills.

Exam results

The exams of the second and third quartile have taken place and the graphs in *Figure 2* show the percentage of students that have passed the exam. Due to the Graduate School, a distinction is made between results of the new

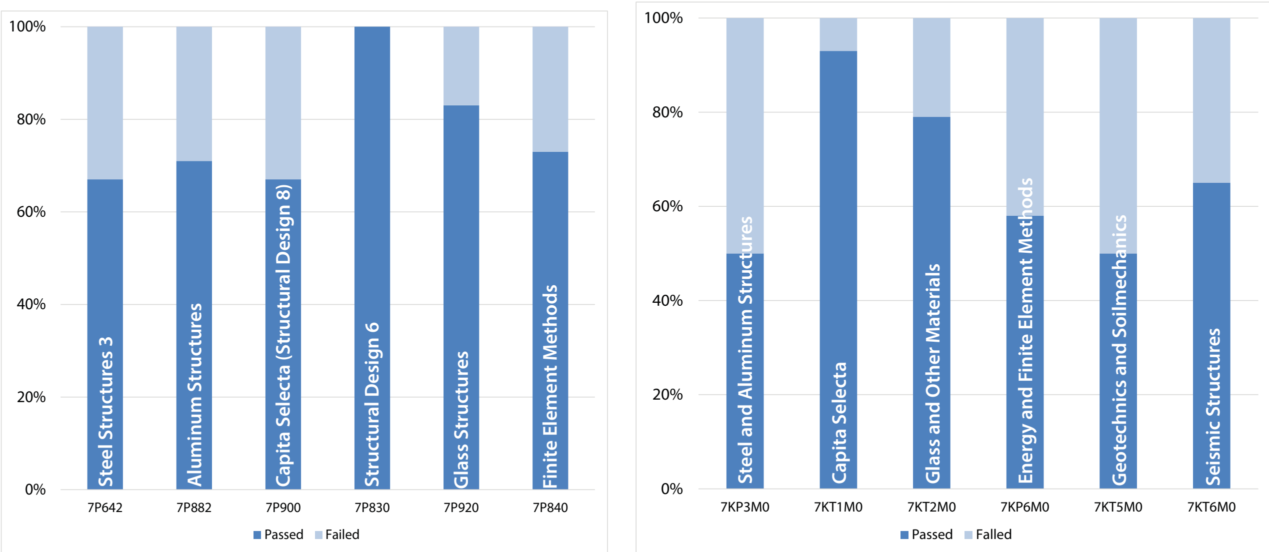

Figure 2: Exam results - Old style (left) and Graduate School (right)

Column

Structural Heroes

Hans Lamers

Structural Design is the best choice. In what way, you may ask? Well, in every way! The knowledge of materials, properties, mechanics, dynamics, finite element methods, and energy principles are all ingredients for a Structural Design student to somehow become a successful engineer and start a blazing career. The ingredients of the Master courses capacitate the students for different engineering jobs, for instance in the building industry or in the field of civil engineering, but also in agriculture, shipping industry, aviation (drones), and offshore. Young people with versatile inventive minds. And how about building a bridge! A bridge composed of many hundreds of blue beer crates. Unfortunately with empty bottles. These are my structural heroes of KOers, with or without a new record for the free span. At this very moment, I hope and believe they will break the record. Together with the conceited French I like to say:

"Chapeau, chapeau, un chapeau emplumé!"

Colophon

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Cover

Ormonde offshore wind farm, Irish Sea (UK)
Photo by: Tony West, Vattenfall

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