Concrete Structures

Research and Education

TU Delft

Information booklet 2021 - 2022

Heydar Aliyev Cultural Centre, Baku, Azerbaijan, Zaha Hadid Architects
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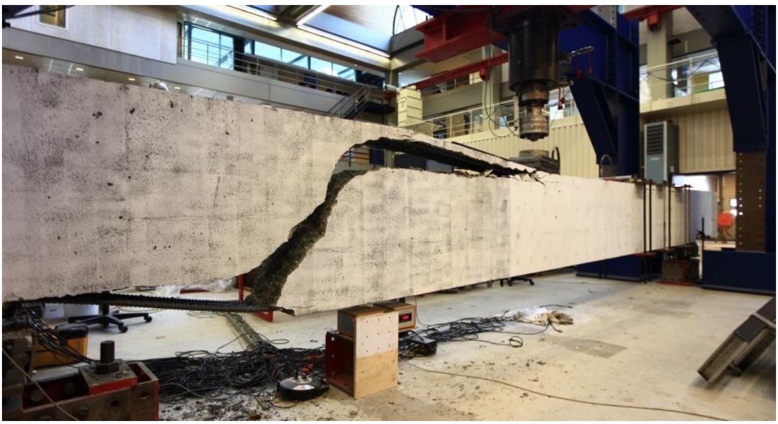
Cover image: Concrete Laboratory: Shear test on 12 m long T-shaped prestressed concrete girders

Preface

This booklet is published by the group of Concrete Structures[1] of the faculty of Civil Engineering and Geosciences of the Delft University of Technology. The booklet is published to provide information for bachelor and master students who wish to specialise in concrete structures.

Within this document an overview is given of the activities of the group of Concrete Structures. These include research activities as well as education. With regard to education this booklet is intended to be a guiding document for (future) master students of Structural Engineering with the specialisation 'Concrete Structures'. At the same time it can help students to choose courses and to make a planning for the master's phase.

December 2021



[1] See the Concrete Structures website: tudelft.nl/en/ceg/about-faculty/departments/engineering-structures/sections-labs/concrete-structures/

Shear testing of a concrete girder in the Concrete Laboratory

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1 Introduction

Concrete is the most used construction material worldwide. An estimated amount of 7.5 billion cubic meters of concrete is produced each year, which is more than one cubic meter for every person on earth[1]. The amount of concrete used worldwide, ton for ton, is twice that of steel, wood, plastics, and aluminium combined. This can be explained by the advantages of the material, such as worldwide availability, easy execution on site, freedom of shape, durability, long service life and good fire resistance. Concrete can therefore be found in a large variety of structures such as architectural structures, housing, foundations, brick/block walls, pavements, highway bridges/overpasses, tunnels, parking structures, dams, pools/reservoirs, pipes and even boats. However, concrete is not just 'one material'. Several types of mixtures exist, each with their own special material properties, such as (ultra) high strength concrete, lightweight concrete, strain hardening cementitious

Bridge De Lentloper, Nijmegen, photo by Thea van den Heuvel/DAPh.

[1] *"Minerals commodity summaries". United States Geological Survey.*

composites (‘flexible concrete), alkali-activated (geopolymer, “green”) concrete, self-compacting concrete, etc. And all structures made with these types of concrete need to comply to the demands with regard to strength, stability, durability and serviceability, while they are subjected to various loads and environmental conditions during their lifespan.

The field of concrete structures covers the construction - including structural design, calculations and execution - and maintenance of reinforced and prestressed concrete structures. There are many new challenges that on the one hand deal with questions like how to apply new types of concrete in a safe and sustainable way in new structures. On the other hand, how to deal with the large amount of existing structures and their maintenance, needs to get a lot of attention nowadays. The chair of Concrete Structures at Delft University of Technology contributes to these challenges by the research projects that are performed by the group and by using these latest investigations and developments when educating young engineers.

1.1 Chair

The group of Concrete Structures is part of the Faculty of Civil Engineering and Geosciences of Delft University of Technology. The group was already part of Delft University of Technology even before it became a university. The chair was first appointed at the ‘Technische Hogeschool van Delft’ to prof.ir. J.A. Bakker in 1918. In that time reinforced

Our place in the organisation:

- Delft University of Technology
- Faculty of Civil Engineering and Geosciences
- Department ‘Engineering Structures’
- Section ‘Concrete Structures’

Construction of the Faculty of Civil Engineering, 1969, Delft.

concrete was still a relatively new building material. By the time the Technische Hogeschool became a University in 1986, the group had become a national and international renowned group due to its contributions to guidelines for reinforced concrete as well as prestressed concrete. Yearly, many activities were organized like symposia and excursions and, together with the 'Betondispuut[1]', the concrete canoe race. In the past decades the focus of the group was not only on structural behaviour of concrete structures, but also on the development of new types of concrete, like high strength concrete and self-compacting concrete. Furthermore, the group stimulated the development of codes and with prof.dr.ir. J.C. Walraven and prof.dr.ir. D.A. Hordijk, it contributed strongly to the development of international codes, like Eurocode 2 and the *fib* Model Code. Since many decades the group is famous for the research on failure mechanisms and especially shear.

[1] *Since 2015 merged with two other student associations in U-BASE (see 4.4).*

Today the group is chaired by prof.dr.ir. Max A.N. Hendriks. Changes in the society and the field of concrete design have their consequences for the focus in research and education. Buildings and bridges build in the sixties and seventies are now more than 50 years old and several of them require reassessment to ensure their safety. Additionally, we are aware of urgency for sustainable construction, considering circularity and CO_2 neutrality. New types of concrete containing new types of binders, reinforced with fibres, self-sensing, strain-hardening, etc. are developed rapidly, however, guidelines on safe structural application of these new 'materials' are lacking. The group of Concrete Structures contributes to these societal challenges by initiating research projects, like proof loading of existing viaducts, development of bridges for the future "Smart bridge", developing models for structural behaviour of concrete, etc. Furthermore, it is our goal to educate students following the latest standards and developments. A specialisation in Concrete Structures provides a broad knowledge in the field of concrete engineering, including concrete technology, execution of structures, design, prestressing, etc. In our master courses we do not just focus on applying codes to standard situations and structures, but on teaching students to find solutions for each situation or special structures. Concrete engineers that graduate in our group can really contribute to society by innovative designs and safe structures.

Objectives:

- Supplying students proper tools and first experiences to become a good and responsible structural engineer being able to design adequate and safe concrete structures based on insight in structural behaviour of all types of concrete, while furthermore being able to communicate and work together with the many other parties active in the building process.
- Performing research directly serving or related to societal challenges.

Bridge over the Amsterdam-Rijn Canal for the new connection A1-A9, Diemen
bouwwereld.nl

In Chapter 2 an overview of the research lines and activities of the group of Concrete Structures is given. For students this chapter might also provide ideas for their graduation project. In Chapter 3 the educational program provided by the group of Concrete Structures is described. This includes information on the bachelor program, the master specialisation ‘Concrete Structures’ and the practicalities surrounding the Master’s thesis. Chapter 4 provides useful addresses, telephone numbers and/or websites of employees and important institutions related to the group of Concrete Structures.

2 Research

This chapter focusses on the research performed by the group of Concrete Structures. The research projects are set up in relation to the three main research lines of the group (Section 2.1). Often the projects are performed in the Concrete Laboratory (Stevin laboratory). Information about this facility and the research projects can be found in Section 2.2. Most research projects are performed by graduate students or PhD-students in combination with a technician and a scientific staff member. Additional information on our PhD research can be found in Section 2.3.

2.1 Research lines

The research projects executed in the group of Concrete Structures are set up to contribute to the three main research lines of the group.

Assessment of existing concrete structures

The majority of the existing concrete bridges and viaducts in the Netherlands is approaching the initially intended technical service life. These bridges have to be assessed, to determine whether the structural capacity is still sufficient for an extended service life. At the same time, traffic loading has increased over the past decades which leads to increased loads compared to the design loads in the original calculations. Reassessments are executed in order to try to preserve these structures, because replacement is expensive and not always necessary. Furthermore, buildings often require renovation or refitting, e.g. because of demographic changes. In that case the assessment of the existing concrete load-bearing structure can be required.

Proof loading of the Ruytenschildtbrug in 2014, using 380 ton of counterweights of cranes, Vierhuizen.

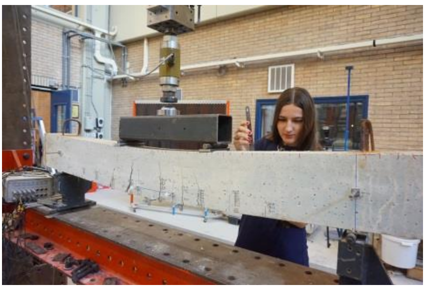
The research projects within this research line aim at determining the real capacity of structures. Laboratory tests are performed to determine the actual failure loads for different failure mechanisms, depending on, for instance, reinforcement configuration or reinforcement type. Furthermore, tests are performed in situ, on real structures, to register their response behaviour and find out whether there could be higher capacity due to cooperation of structural elements. It is the intention of the group to prepare a guideline for safe and adequate proof loading of existing concrete structures, so that in future this type of assessment can be performed by market parties.

Application of new types of concrete

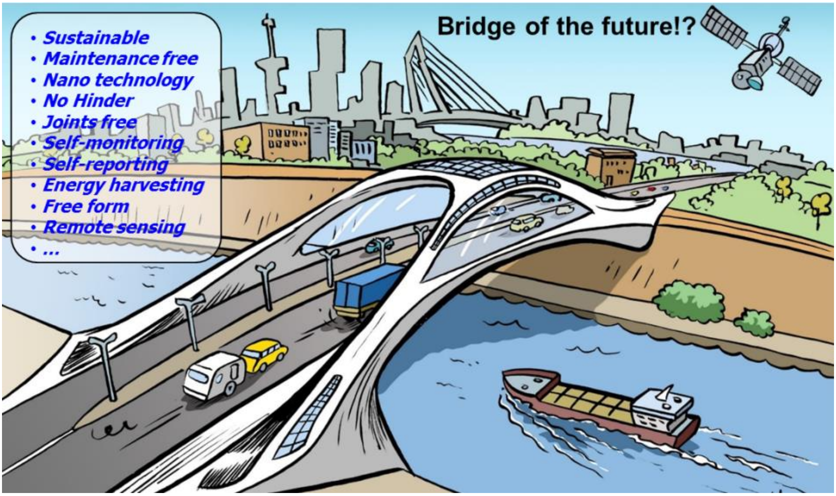
During the past decades, many new types of concrete are developed, such as Ultra-High-Performance-Concrete (UHPC), Strain-Hardening-Cementitious-Concrete (SHCC) and Alkali-

Activated (Geopolymer) Concrete. These new and innovative types of concrete offer great opportunities for society to construct in a more economic, durable and sustainable way. Applications of the new developed types of concrete in real structures are still rather limited. Several reasons can be mentioned for this, like uncertainty about structural behaviour, lacking of codes and models to reliably predict their behaviour. First of all, it should be investigated and demonstrated where and how the materials can be advantageously applied, while the advantage can be in sustainability, economy, durability, aesthetics, less or no maintenance, less hinder during execution, etc. For instance, the tendency towards more slender bridges and viaducts can be a reason to apply UHPC. Or, the future might lie in hybrid concrete structures, where innovative and conventional concretes, are combined, such that innovative, advanced concrete types are applied only on “highly demanding” locations (e. g. in cover, highly loaded tension zones).

The research projects within this research line aim at demonstrating the behaviour of structures and structural elements made with these new types of concrete. By initiating projects to actually apply these materials on laboratory scale or in real structures, experience and confidence with the materials is increased. At the same time, the research outcomes contribute to new guidelines or standards for the application of these materials.



MSc thesis works of Silke Prinsse (Geopolymer concrete) and Zhekang Huang (SHCC hybrid structures).



Smart Bridge, the bridge of the future including i.e. UHPC, energy harvesting capabilities and monitoring.

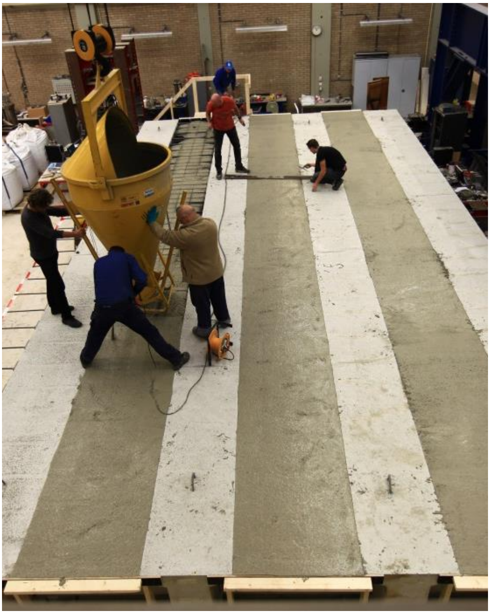
Monitoring

The third research line is Monitoring which deals with developing and assessing new monitoring techniques for reinforced and/or prestressed concrete structures. Currently, the group is busy with investigating the potential of Piezoelectric sensors, so called Smart Aggregates, Acoustic Emission technique, Optical fibres, etc.

2.2 Laboratory

An important facility of the group of Concrete Structures is the concrete laboratory. The laboratory is part of the Construction Laboratory of the department ‘Engineering Structures’. The laboratory enables the group to perform research on characteristics of new types of concrete and on large scale concrete structures.

In the Concrete Laboratory a concrete casting area is present, with several small scale mixers with capacities ranging from 1 up to 150 litres. The availability of several types of cement, various sizes of sand and aggregates and different types of fillers enables research on mixture design as well as the casting of small structural elements for testing of mechanical properties of new concrete types.



Furthermore, the Concrete Laboratory has a special floor for static and/or dynamic testing by using space frame. The frame is prestressed to the floor which enables testing concrete structures by loads up to 10.000 kN. Often tests are performed on small scale beams or elements because of economic reasons. However, when necessary, elements can be up to 40 meter long, 20 meter wide and/or 8.5 meter high.

Casting of a bridge deck in the Concrete Laboratory (Approach bridge of the Brienenoord Bridge Rotterdam, scale 1:2).

Other facilities of the concrete lab include:

- Digital Image Correlation (DIC), Thermal camera, Optical fibres, Surface scanner - Profilometer and 3D scanner
- Concrete drilling and sawing workshop, Fog room and climatised rooms for testing of e.g. shrinkage and creep.
- Temperature Stress Testing Machine for testing hardening concrete subjected to restrained deformations.
- Equipment for testing of rheological properties of fresh concrete and mechanical properties of the hardened state.

An overview of all mechanical testing equipment can be found on labs.tudelft.nl.

Most of the research executed in the Concrete Laboratory is financed by the Dutch government or external companies (see frame for our financial resources). When you have a research question and you are interested in having the tests performed by the Concrete Laboratory of Delft University of Technology, please contact Prof.dr.ir. M. Hendriks for an offer or introductory meeting.

Financing of the research projects in our laboratory:

- European governmental funding
- Dutch governmental funding via NWO, STW
- Dutch governmental organisations such as RWS, provinces
- Companies such as contractors, TNO
- Funding from Delft University of Technology (direct funding)

2.3 PhD students

Most of the research conducted in the Concrete Laboratory is directly related to PhD-research on one of the three research lines of ‘Assessment of existing structures’, ‘Application of new types of concrete’ and ‘Monitoring’. A PhD student investigates one topic for a period of four years. During that time experiments can be performed in order to investigate a phenomenon or explain the behaviour. In addition to that, the PhD student has time to analyse data thoroughly and make a model to explain the experimental results in a better or more comprehensive way. Sometimes finite element models are used, but also analytical or physical models are developed. PhD students work also on their personal development via a training program of the Graduate School of TU Delft.

Over the past, many PhD students of the group of Concrete Structures have contributed to improving our knowledge and understanding of concrete structures and their behaviour. C.B.M. Blom, J. Fellinger, S. Grünewald and Y.Yang have received the *fib* Achievement Award for Young Engineers for their PhD theses. In 2017, the idea and paper of our PhD student Albert Reitsema was ranked 4th at the World Innovation in Bridge Engineering (WIBE) Prize. Recently our PhD student Shozab Mustafa and visiting PhD student Dawei Gu won a *fib* International competition on Modeling of Recycled Aggregate Reinforced Concrete by using discrete type Lattice Model. The group is internationally renowned and often asked to contribute to new guidelines like the Model Code or new recommendations for Ultra-High-Performance Concrete.

I started my PhD project in February 2014 as a part time researcher (60%). The other days I work at 'Van Hattum en Blankevoort' as a senior structural engineer. I followed my master studies at TU Delft much later than the average student – after nine years of work experience as a structural engineer. Nevertheless, during my studies I was fascinated by the methods and approaches and I gained the idea of continuing in the field of research. So, when a few years later an interesting PhD project on existing concrete structures crossed my path, the TU Delft, Van Hattum and Blankevoort and I quickly came to an agreement.

Sebastiaan Ensink

The topic of my thesis is compressive membrane action in the deck of girder bridges. With these type of bridges the girders, the crossbeams, and a cast in place deck work together. Due to transverse prestressing the capacity of the system becomes much higher than could be expected based on the strength of the individual girders. It is my job to quantify this phenomenon by using experiments as well as non-linear finite element modelling (FEM). For me and my company it is important that this topic is practically relevant and contributes to increasing our knowledge on recalculations and reassessments of existing concrete bridges. Furthermore, it is strongly motivating for me to work on several interesting small 'projects' within my research project. We organized an international contest to predict the capacity of individual concrete girders by non-linear FEM calculations and then we really tested the girders in the laboratory. To test these 12 meter long and 1.3 meter high girders to failure by loading them up to 3000 kN was an unique experience.

Shear testing of a prestressed concrete girder for the PhD-research of ir. S.W.H. Ensink.

Examples of research projects within the line of existing structures are ‘Shear behaviour of reinforced concrete members without shear reinforcement’, ‘Shear in reinforced concrete slabs’, ‘Shear strength of prestressed girders uncracked in flexure’, ‘Compressive membrane action in prestressed concrete deck slabs’, and ‘Smart proof loading of concrete structures by using acoustic emission measurements’. More information on the topic of ‘compressive membrane action in the deck of girder bridges’ can be found in the interview with ir. S.W.H. Ensink in the frame.

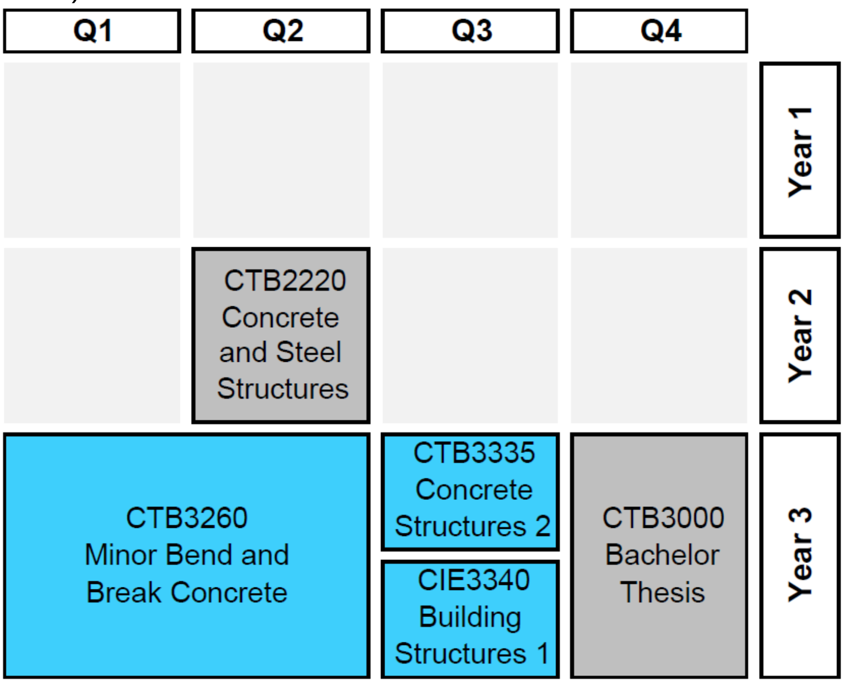
The research line of ‘Application of new types of concrete’ contains topics such as ‘Smart bridge’, ‘Rotation capacity of self-compacting steel fibre reinforced concrete’ and ‘Static and fatigue behaviour of high strength fibre reinforced concrete’. For an overview of the current PhD projects please check the profiles of our PhD students on the Concrete Structures website.

3 Education

In this chapter students in all phases of their civil engineering studies can find information on the courses completely or partially provided by the group of Concrete Structures. Courses can change over time – detailed and up to date information can be found via studyguide.tudelft.nl.

3.1 Bachelor

To prepare students for the master specialisation 'Concrete Structures', the group of Concrete Structures offers several courses within the bachelor program of Civil Engineering (see the overview below).



** compulsory courses are given in grey*

Overview of Concrete related courses within the study scheme for BSc students

Some courses are either compulsory (CTB2220) or strongly recommended (CTB3335, CIE3340), because the content of these courses is required as pre-knowledge for the master 'Concrete Structures'. In this section an overview of the bachelor courses provided by the group of Concrete Structures is presented.

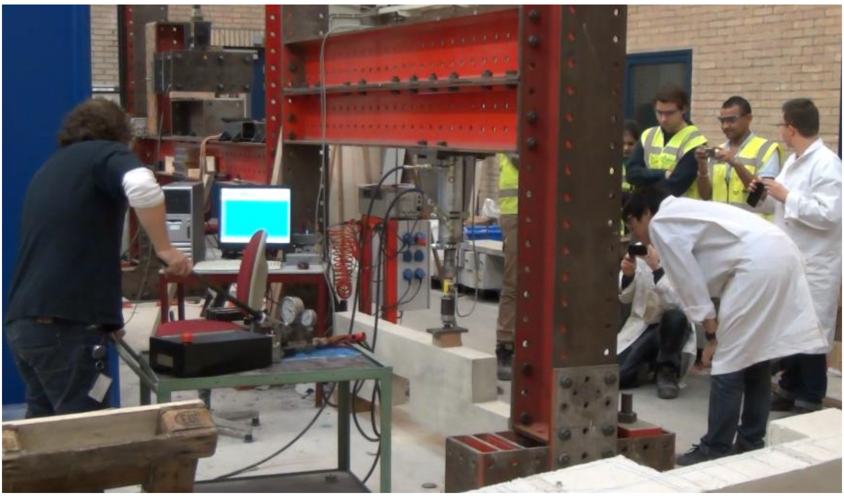
CTB2220	**Concrete and Steel Structures**	5 ECTS
Instructor:	Ir. P.A. de Vries	Year 2, period 2
	Dr.ir. H. van der Ham	Language Dutch

In this course students are introduced to the European codes and methods to assess the serviceability and safety of statically loaded, linear, prismatic structural elements (such as beams and columns) of concrete and steel. The principles of designing with steel and reinforced concrete are covered, as well as a more general part on building regulations, safety philosophy/concept, loads, load combinations, load and material factors and robustness of structures. Students learn to design and to assess the performance of cross-sections subjected to an axial force, bending moment and a shear force. Relevant material properties of concrete and steel are introduced. Furthermore, attention is paid to connections between structural elements, stability of elements, and the assessment of steel trusses and frameworks. In the concrete part topics like crack width control, detailing, rebar and anchorage technology are addressed.

Atlas Building, Wageningen University and Research Centre

CT3260	**Bend and Break Concrete**	5 ECTS
Coordinators:	Dr.ir. H. van der Ham Dr.ir. M.C.M. Bakker	Year 3, period 1,2 Language Dutch

This course is part of the Minor Bend and Break and can only be followed as a part of this Minor. In this course students will design, build and test their own concrete beam in groups of 4 students. Lectures on concrete design and the use of SCIA Engineer will help the students to calculate the most efficient (rebar) configuration of their beam. The calculations are based on each group's own material properties from the testing of rebars and design of their concrete mixture. Students get graded based on the strength of their beam, their report of the design, calculations, tests and failure evaluation, and an individual test. For more information about the Minor Bend and Break students can check the website or contact the coordinators.



Testing the capacity of the beam during the Bend and Break Concrete Course

CTB3335	**Concrete Structures 2**	4 ECTS
Instructor:	Dr.ir. M. Lukovic	Year 3, period 3
	Dr.ir. H. van der Ham	Language English

The main goal of this course is to learn to apply calculation methods to design and assess the serviceability and safety of reinforced structures and statically determinate prestressed structures. The course contains an introduction on the differences in the design of reinforced concrete and prestressed concrete. For reinforced concrete the focus is on the design of slabs spanning in one and two directions. This includes different calculation methods for the internal forces, such as an elastic analysis and the equilibrium method for slabs supported by beams and flat slabs. For punching shear, the theory of resistance as well as the application of reinforcement, are covered. Furthermore, crack width control based on the tensile member model in both the crack formation stage and the stabilized cracking stage is included. For prestressed concrete the focus is on the design of statically determinate prestressed concrete girders. This includes the principles and materials, and the concept of prestressing as an external load. Furthermore, prestress losses caused by friction, slip, wedge set, creep, shrinkage and relaxation are discussed. Ultimate limit state checks such as bending moment capacity are included as well as the detailing of reinforcement for stresses caused by the introduction of prestressing forces.

Excursions Concrete bridges 2015 to the bridge over the Amsterdam-Rijn Canal (left) and U-Base excursion 2018 to the cement factory and quarry ENCI in Maastricht (right)

CTB3340	**Building Structures 1**	4 ECTS
Instructor:	Dr.ir. S. Pasterkamp	Year 3, period 3
	Dr.ir. H. van der Ham	Language: Dutch

The course contains the following topics: Industrial single storey structural buildings in concrete, timber and steel; housing in masonry, concrete and timber; foundations. After completing the course, students know specific functional, structural and constructional aspects of single storey industrial buildings and housing, in steel, timber and concrete. Furthermore they can implement knowledge in structural design of single storey industrial building.

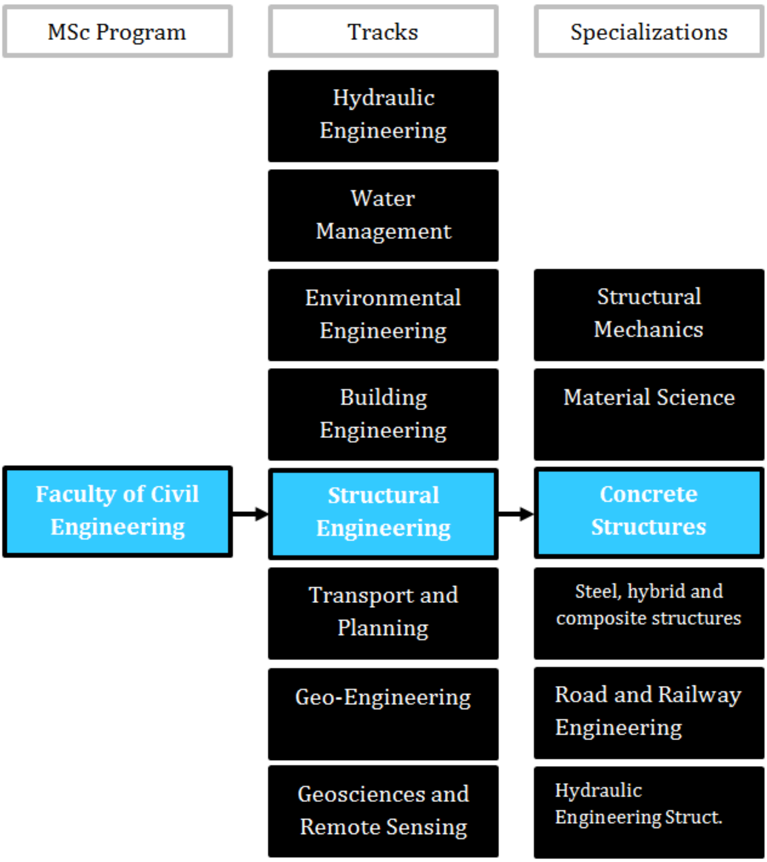
CTB3000	**Bachelor Thesis**	10 ECTS
Coordinator:	Y. de las Heras	Year 3
	Supervisor from the	Language: Dutch
	Concrete Structures group	Or English

CTB3000 is a 10 ECTS individual graduation project. To specialise in concrete structures students can choose a concrete related topic from afstudeeropdrachten.citg.tudelft.nl/ and contact the graduation coordinator of Structural Engineering (dr.ir. P.C.J. Hoogenboom) and main supervisor. Most topics require that students have passed CTB3335 - Concrete Structures 2. Suggestions for topics may come from students as well. The content of the project is defined or approved by the appointed examiners. Another option is to graduate as building engineer with a concrete related subject.

The assessment committee will meet at the start to define the project, during the project for a mid-term assessment and at the end for a final assessment. The student is responsible for these meetings and the notes from these meetings. The student will hand in a written report including the notes of the meeting and a self-evaluation of the learning process.

3.2 Master

The group of Concrete Structures offers the master specialisation ‘Concrete Structures’ within the graduation track ‘Structural Engineering’. The information in this part of the booklet is meant as guidance for students to make a study planning. The official course and examination regulations are always decisive. These can be found at Legal Position/Regulations/TER/Civil Engineering and Geosciences on studenten.tudelft.nl.



Specialisation on Concrete Structures

In this section an overview of the courses which should be taken according to the examination regulations[2] is presented. Furthermore, for the courses provided by the group of Concrete Structures course descriptions can be found. Additional information is available via studyguide.tudelft.nl. Furthermore, students are advised to enrol each course via Brightspace for the latest news and updates.

3.2.1 Overview Master track Structural Engineering, specialisation 'Concrete Structures'

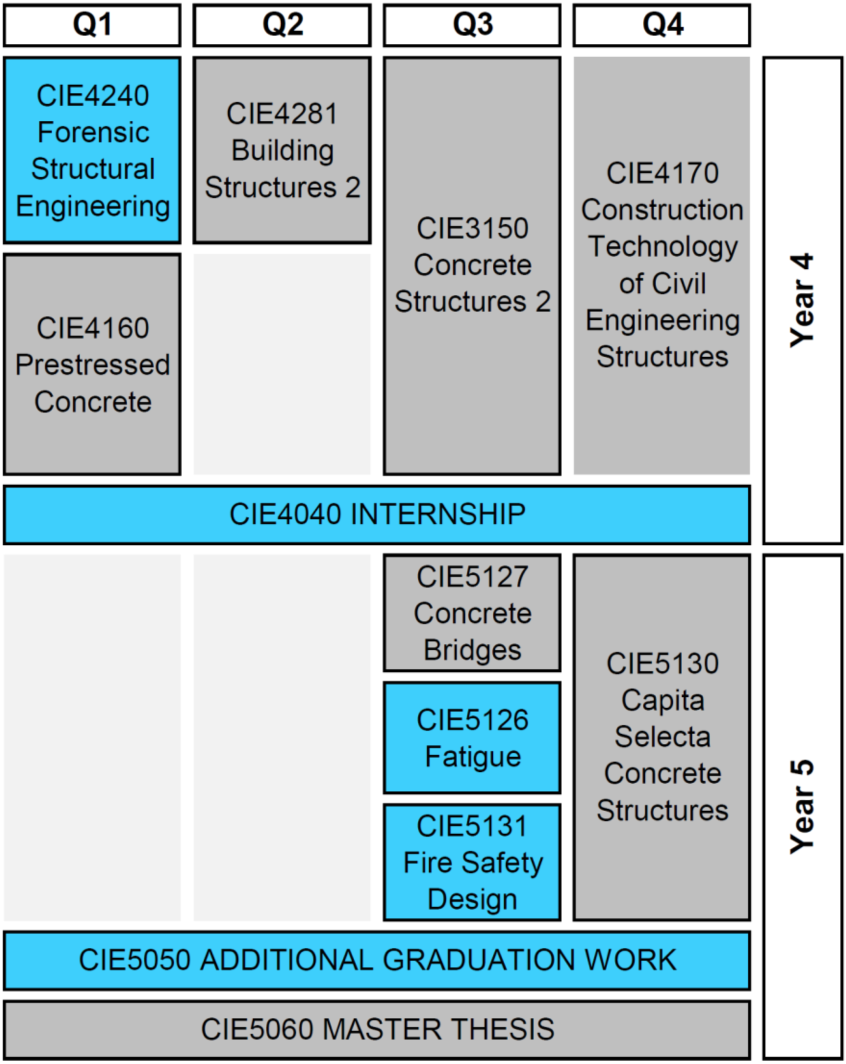
Table 1 provides an overview of the required courses to graduate as structural engineer with a specialisation 'Concrete Structures'. The general program (36 ECTS) and concrete related courses (24 ECTS) are compulsory. Within the 20 ECTS electives students are free to compose their own study program. However, students who did not take CTB3335/CIE3150 Concrete Structures 2 in their bachelor should follow it in their master as pre-knowledge for i.e. CIE4160 'Prestressed Concrete' and CIE4170 'Construction Technology of Civil Engineering Structures'. Furthermore, CIE4240 'Forensic Structural Engineering' and CIE5126 'Fatigue' are strongly recommended to deepen the students' knowledge on possible failure mechanisms of concrete structures. The overview of concrete related courses within the master program is also given.

[2] Regulations: tudelft.nl/studenten/faculteiten/citg-studentenportal/onderwijs/onderwijsinformatie/regelingen-oer-regels-en-richtlijnen/

Table 1 Overview of courses for the specialisation ‘Concrete Structures’

code	subject	ECTS	Period 1	2	3	4
General program Structural Engineering: 36 ECTS						
WM0312CIE	*Philosophy, Technology Assessment and Ethics for CT*, **or**	4				■
CIE4510	*Climate Change: Science & Ethics*	4		■		
CIE4100	Materials and Ecological Engineering	4		■		
CIE4110	Timber and Timber Structures 1	4	■			
CIE4115	Steel Structures 2	4	■			
CIE4121	Steel Structures 3	4			■	
CIE4140	Structural Dynamics	4			■	
CIE4160	Prestressed Concrete	4	■			
CIE4180	Plates and Slabs	4		■		
CIE4190	Analysis of Slender Structures	4	■			
Specialisation ‘Concrete Structures’: 24 ECTS						
CIE4170	Construction Technology of Civil Eng. Str.	4				■
CIE4281	Building Structures 2	4		■		
CIE5110	Concrete – Science and Technology	4		■		
CIE5127	Concrete Bridges	4			■	
CIE5130	Capita Selecta Concrete Structures	4				■
CIE5148	Computational Modelling of Structures	4	■			
Electives: 20 ECTS Several options, including:						
CIE3150	Concrete Structures 2 (required when not in BSc)	4			■	
CIE4040	Internship	10	□	□	□	□
CIE4061	Multidisciplinary Project	10	□	□	□	□
CIE4240	Forensic Structural Engineering (recom.)	3	■			
CIE5050	Additional Master Thesis Project	10	□	□	□	□
CIE5126	Fatigue (recommended)	3			■	
CIE5131	Fire Safety Design	3			■	

Master Thesis Project: 40 ECTS



** compulsory courses for the specialisation ‘Concrete Structures’ are given in grey*

Overview of Concrete related courses within the study scheme for MSc students

3.2.2 Master courses

CIE3150	**Concrete Structures 2**	4 ECTS
Instructor:	Dr.ir. M. Lukovic Dr.ir. H. van der Ham	Year 3, period 3

The course CIE3150 'Concrete Structures 2' is meant for Master students, who did not take the course CTB3335 'Concrete Structures 2' during their Bachelor studies at Delft University of Technology.
If you are a master student wishing to take CIE3150, you will be taking the same course and examination as CTB3335, with only one exception: when you register for your examination via OSIRIS, you have to register for the exam of CIE3150.

The main goal of this course is to learn to apply calculation methods to design and assess the serviceability and safety of reinforced structures and statically determinate prestressed structures. The course contains an introduction on the differences in the design of reinforced concrete and prestressed concrete. For reinforced concrete the focus is on the design of slabs spanning in one and two directions. This includes different calculation methods for the internal forces, such as an elastic analysis and the equilibrium method for slabs supported by beams and flat slabs. For punching shear, the theory of resistance as well as the application of reinforcement, are covered. Furthermore, crack width control based on the tensile member model in both the crack formation stage and the stabilized cracking stage is included. For prestressed concrete the focus is on the design of statically determinate prestressed concrete girders. This includes the principles and materials, and the concept of prestressing as an external load. Furthermore, prestress losses caused by friction, slip, wedge set, creep, shrinkage and relaxation are discussed. Ultimate limit state checks such as bending moment capacity are included as well as the detailing of reinforcement for stresses caused by the introduction of prestressing forces.

CIE4160 **Prestressed Concrete** 4 ECTS
Instructor: Dr.ir. S.C. Barbosa Nunes Year 4, period 1

This course deals with the fundamental aspects and points of interest in the design and detailing of prestressed concrete structures. A detailed overview of different techniques and their characteristics is presented, covering pre-tensioning, post-tensioning, partially prestressing, external prestressing and bonded and unbonded tendons. The equivalent prestressing load approach as a general procedure in the flexural analysis of statically determinate and statically indeterminate structures is introduced. The effects of shrinkage, creep and relaxation on loss of prestressing and redistribution of forces are discussed. Special attention is given to the crack width control in partially prestressed members and the bending moment and shear resistance in general. Strut and tie models are used for shear resistance and to introduce forces in disturbed regions. Detailing of prestressed structures is discussed.

Prestressing with post-tensioned steel © beeldbank bouwen met staal

CIE4170 **Construction Technology of Civil Engineering Structures** 4 ECTS
Instructor: Ir. J.P.G. Ramler Year 4, period 4

Understanding the nature and implication of selected structural design aspects such as shape, dimensions, material and design approaches on the one hand and the construction considerations such as execution methods, schedules and costs on the other hand and their interdependency in an integrated building process of a concrete structure. This involves thorough knowledge and understanding of project characteristics, control systems, methodology of the process and supporting systems in order to optimise cost driver aspects in conceptual and final design.

CIE4240 **Forensic Structural Engineering** 3 ECTS
Instructor: Dr.ir. K.C. Terwel Year 4, period 1

The main goal of this course is to understand and explain important structural failure mechanisms in various materials and to be able to come up with design measures to avoid these problems. Failure mechanisms can be collapse due to insufficient strength or stability, cracks, unacceptable deformations or settlements that are caused by inadequacies in design, detailing, unexpected circumstances or construction errors. The following topics are covered:

- Structural damage: what is damage? Performance criteria and codes. How often does failure occur? What are technical causes? What are human and organizational causes?
- Damage in concrete: e.g. temporary structures, reinforcement in ridges
- Damage in steel: e.g. connections and instability
- Damage in timber: e.g. connections
- Damage in finishing structures: e.g. leakage and connections
- Damage in foundations: e.g. deterioration of timber piles, unequal settlements
- Methods and instruments for investigation: process of investigation. Analysis of factual data, testing of specimen, calculations, reporting.

- Legal aspects: liability, insurance, court, expert witnesses

CIE4281 Building Structures 2 4 ECTS
Instructor: Ir. S. Pasterkamp Year 4, period 2

An introduction on multi-storey buildings in steel and concrete is given. Examples from practice are dealt with. Design principles for building structures are treated. In the course, both concrete structures built in situ and precast structures are discussed. Important components of buildings like floor types, foundations and their role with regard to stability are dealt with. For precast concrete structures the design principles and considerations are given. Structural systems and stability are systematically explained. The production of several types of elements and its relation to structural design is discussed. Further point of attention are the connections between precast elements. Buildings which have been realized are used for explanation and illustration. The use of structural steel in multi-storey buildings is highlighted, including structural concepts. Methods for realizing stability are demonstrated. The principles of braced and unbraced frames are treated, including the influence of the connection characteristics on the overall behaviour. Hybrid and composite structures are discussed and means for fire-protections are given. Manufacturing and erection are treated.

Glass Palace, Heerlen © beeldbank bouwen met staal

CIE5126 **Fatigue** 3 ECTS
Instructor: Dr. F. Kavoura Year 5, period 3
Dr.ir. Y. Yang

The student will learn how to design fatigue loaded steel, aluminium, concrete and timber structures. Two-thirds of the course is spent on lectures, while the remaining part is dedicated to exercises. The main topics are:

- Fatigue actions: basic principles; determination of stresses and stress intensity factors; stress history.
- Fatigue resistance: basic principles; classified structural details; fatigue strength modifications; resistance against crack propagation; resistance of joints with weld imperfections.
- Fatigue assessment: general principles; S-N curves; crack propagation calculation; service testing; parameters influencing the fatigue strength of steel, aluminium, concrete and timber connections and structures; safety considerations and synthetic fatigue curves.

CIE5127 **Concrete Bridges** 4 ECTS
Instructor: Dr.ir. Y. Yang Year 5, period 3

Students will learn how to choose between the different types of bridges, estimate the construction depth and the different methods of construction. Starting point is to describe the structures of the most common types of bridges.
Much attention will be paid to the historical development in prefabricated girders and concrete cross-sections cast in situ. The method of load distribution will be discussed in detail, as well as the design of expansion joints and the use of structural bearings. Special attention will be focused on bridges with long spans such as cable stayed bridges. Typical vibration problems are discussed. Finally, the use of high strength concrete and the effects on the design are explained. Two-thirds of the course consists of lectures, while the remaining one third is dedicated to case studies. Students can perform case studies individually or in pairs. They have to be finalized in order to be eligible for the oral exam.

Ultra-high performance bridge FDN engineering, Rotterdam

CIE5130	**Capita Selecta Concrete Structures**	4 ECTS
Instructor:	Prof.dr.ir. K. van Breugel Dr.ir. M. Lukovic	Year 5, period 4

This course is dedicated to a number of particular aspects of concrete structures.
An aspect of the behaviour of concrete structures that often is underestimated is the role of temperature effects. Cracking of concrete can occur due to imposed deformations as a result of temperature gradients, like generated by solar radiations. Temperature effects occur also in the period that the concrete hardens. Due to chemical reactions associated with the hydration of cement, temperature gradients occur from inside and can lead to cracking when the strength of the concrete does not keep up with the tensile stresses developed. Cracks reduce the quality of a structure (tightness, durability) and excessive cracking should therefore be avoided. The principles of crack width control in relation with temperature effects are addressed.
Finally, the design of concrete structures with a protective function is treated. Such structures require a design against extreme types of loading, like impact, blast and extremely low temperatures (for instance inherent to the storage of LNG).

CIE5131	**Fire Safety Design**	3 ECTS
Instructor:	Dr.ir. G.J.P. Ravenshorst	Year 5, period 3

General introduction to the fire safety design of buildings. Emphasis on structural fire safety and regulations (national & European). Basic principles of fire safety design of buildings, consequences of fire, various options for fire safety design. Phenomenological description of the fire process, schematisation and modelling of the fire process, mechanisms of fire propagation. Material behaviour (reaction-to-fire) and structural behaviour (resistance-to-fire) and the options to quantify this behaviour. Emphasis on concrete, steel and timber structures. Smoke issues: smoke production, smoke spread and smoke control. Active measures (automatic suppression, detection). National fire regulations: Building Decree (Bouwbesluit), concept, assessment methods, principle of equivalence. European standardisation (Construction Product Directive, Eurocodes, Euroclasses). Recent developments regarding the fire design of buildings (Fire Safety Engineering).

CIE4040	**Internship**	10 ECTS
Instructor:	M.L.Y.Kraeger-Holland Dr.ing. M.Z. Voorendt Supervisor from the group of Concrete Structures	

The internship consists of a personal project of at least 7 fulltime weeks in an environment of day-to-day practice of civil engineering companies or institutes (contractors, consultancies, government, non-governmental organisations, etc.) in the Netherlands or abroad.

An internship provides the opportunity to get a glance of the technical, social, economic and organizational aspects of civil engineering and/or related fields as a profession. The student is completing a project in which he/she can apply the academic skills and knowledge acquired in earlier education. The student should aim for a project with clear deliverables of a sufficient academic level.

The main objectives are:

- student develops general engineering skills (e.g. knowledge of methods and technical practice including modelling) in a professional setting.
- student develops research skills (e.g. being analytical based on broad and deep scientific knowledge, synthesise knowledge and solve problems in a creative way) in a professional setting.
- student learns to apply technological know-how in an industrial setting.
- student links theoretic knowledge with practice.
- student develops academic thinking skills, writing and reflecting on experiences.
- student puts into practice social and communicative skills when working with colleagues and non-colleagues.
- student gains a more complete insight into his/ her own particular aptitudes in a professional environment.

Internship office

The internship office can assist in finding a company or organisation in the Netherlands or abroad to do your internship. The internship takes two to three months and is rewarded with 10 ECTS. Before starting your internship, the bachelor studies need to be finished. Check the website or Brightspace for additional information and the internship guide.

Contact
Internship office Civil Engineering, room 2.73
Internship coordinators: M. Kraeger-Holland and M.Z. Voorendt

Telephone: +31 15 -2781174
E-mail: stagebureau-citg@tudelft.nl

CIE5050 **Additional Graduation Work** 10 ECTS

Instructor: Y. de las Heras
Ir. T.J. Zitman
Main supervisor from the group of Concrete Structures

Additional Graduation Work is a 10 ECTS individual project that may or may not be related to the MSc Graduation Work, but it must, in any case, be separately distinguished. The content of the project is defined by the appointed examiners. Suggestions may come from students as well.

The student has to set up an assessment committee which consists of at least two supervisors/examiners from different research groups attached to the Delft University of Technology. One of the examiners must be a professor or associated professor. The assessment committee will meet at the start to define the project, during the project for a mid-term assessment and at the end for a final assessment. The student is responsible for these meetings and the notes from these meetings. The student will hand in a written report including the notes of the meeting and a self-evaluation of the learning process.

L'Oceanogràfic Valencia, Spain

3.3 Master graduation

To graduate as ‘Structural Engineer’ with a specialisation in ‘Concrete Structures’ students must finalize the course CIE5060 ‘MSc Thesis’ on a concrete related topic.

CIE5060	**MSc Thesis**	40 ECTS
Instructor:	Ir. T.J. Zitman	
	Ir. C. Kasbergen & Dr. F. Di Maio; Coordinators Engineering Structures Department	
	Supervisor Concrete Structures Group	

To graduate as ‘Structural Engineer’ with a specialisation in ‘Concrete Structures’ students must finalize a MSc Thesis Project, CIE5060, on a concrete related topic. The Master Thesis project consists of a final project, a thesis, a summary of the thesis and a final presentation. If you have not decided on a project yet and are interested in graduating in the Chair of Concrete Structures contact Prof.dr.ir. M. Hendriks, Dr.ir. Y. Yang or Dr. M. Lukovic. They can provide you with additional information on the graduation but also help you finding your ideal topic. Suggestions for topics may also come from students themselves or from companies. To graduate with the Concrete Structures there is a procedure that needs to be followed. Also students from the Building Engineering track can choose a concrete related master thesis topic.

3.3.1 Procedure

Start up

To start up the graduation project please check the CIE-0 Procedure Graduation. This form will guide you through the procedure of graduating. The first two steps are to apply to start with the master project (CIE-1 Application Start MSc) and to contact the graduation coordinators Cor Kasbergen and Francesco Di Maio.

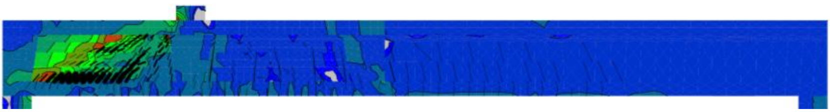
Students need at least 65 ECTS of the MSc completed before they are allowed to start. Furthermore, we require that the course

CIE4160 Prestressed Concrete is finished before the beginning of the graduation project. For certain topics additional demands, like specific courses, can be required by the main supervisor.

Finding a Master thesis topic

Students can choose a concrete related topic on the Brightspace page of Department of Engineering Structures, Section of Concrete Structures (https://brightspace.tudelft.nl/d2l/le/content/180536/Home). If you have not decided on a project yet, we can provide you with additional information. Suggestions for topics may also come from students themselves or from companies. However, students who wish to execute their master thesis at a company should have passed CIE4160 Prestressed Concrete with a mark of 7.0 or higher. Furthermore, students should avoid making any firm agreements with an external host organisation before the topic has been formally approved. **The content of the project is always defined or approved by the appointed examiners**.

When your graduation topic is registered by your supervisor from the Concrete Structures Section, you might start with your thesis.



Model of a concrete beam element and stresses in it calculated by the FEM code ATENA

First month and start meeting

During the first month you work on literature review and your work plan. This work plan will be drawn up in close consultation with your main supervisor. Your work plan should state the topic of your thesis and how you intend to approach the subject matter. Special attention should be paid to the problem description and the **research question**. Another important component of the plan is the time schedule. You should try to produce a realistic time schedule showing firm dates for the completion of the various activities, making allowance for holidays, examination periods, etc.

After about one month you will present your work plan for approval during the start meeting. Only after approval of the work plan, and depending on the intended approach of your project, your main supervisor will appoint the graduation committee. The committee will consist of your main supervisor, a second supervisor from a different chair, and possibly a company supervisor. Please do not try to find (any) second supervisor(s) yourself; he or she will be appointed and asked by your current supervisors. After the start meeting you can complete the “Form Master Examination Programme (CIE-2)” in cooperation with the coordinator.

Course of the graduation project

About half way during your project there will be a mid-term review at which you meet with the thesis committee to discuss the progress of your project. One week before the review, you must submit a progress report to each member of the committee (in hard copy if requested), which must include the schedule for the remainder of the project. The student must make minutes and/or a list of action points for the coming period. During this phase of the project you can meet with the individual members of the thesis committee when that is required for the progress of your project. Ensure that you contact your main supervisor once a month.

At the end there is a final meeting in which ‘green light’ is given to proceed to finishing the project. The date for the final presentation is set then as well. No later than 20 working days prior to the presentation, students should complete the “Application Form Master Degree (CIE-3)”. Students should deliver their final report more than 5 working days prior to the presentation. In that last week the committee will judge the project as a whole. After the final presentation the final mark for the master thesis work is given.

4 Contact and information

The group of Concrete Structures is located at Delft University of Technology, Faculty Civil Engineering & Geosciences in the laboratory Stevin II. We are part of the Department Engineering Structures.

Visiting address:

Stevinweg 1
2628 CN Delft
The Netherlands

Postal address:

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4.2 PhD students & Postdocs

For the most recent overview of PhD students & Postdocs in our group please visit our website: tudelft.nl/en/ceg/about-faculty/departments/engineering-structures/sections-labs/concrete-structures/ and check the sections Staff and Research.

4.3 Supporting staff

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4.4 Related institutions

U-BASE Association

U-BASE is the student association of the masters Building and Structural Engineering at the Civil Engineering and Geosciences faculty at the Delft University of Technology.

Since 1970, the Betondispuut has organized activities for students related to concrete structures. However, times change, more and more hybrid structures are designed in which several types of materials are combined, and also education and the educational structures change. Therefore, a new ‘dispuut’ was founded in 2015. It is a continuation of three associations: Betondispuut, CST-Dispuut and U-dispuut, with the new and more international name ‘U-Base’. U-Base is the abbreviation of ‘United Building And Structural Engineering Association’.

The main objective of U-BASE is to introduce students to the business environment of Civil Engineering and the building and structural engineering practice in particular. To achieve this, U-BASE creates and stimulates relations between students, the university and the construction industry by organising several activities.

These activities include, but are not limited to, excursions to companies and interesting building projects several times a year, a study tour to a foreign country once a year, symposia, workshops and guest lectures and publishing their own magazine the ‘U-Profiel’.

If you wish to participate in any of the activities, or even organize a study tour or help building a concrete canoe, please contact U-Base. For more information you are always welcome to drink a cup of coffee at Stevin II, room 1.35, or you can go to: u-base.org.

Concrete Canoe Race 2016, Prize for the most sustainable canoe (geopolymer)

Het Gezelschap "Practische Studie"

‘Het Gezelschap “Practische Studie” ‘, or in short “PS”, is the student association for students Civil Engineering of Delft University of Technology. “PS” organizes study trips, lectures from companies, symposia and other activities such as bridge building challenges. Furthermore, the association stands up for the quality of education at the faculty of Civil Engineering and Geosciences. They evaluate courses, advise when new measures are introduced and provide study materials for students.

More information can be found on practischestudie.nl.

Study Advisors CEG

The study advisors give advice and counselling on

- Choosing an academic program (subjects)
- Academic planning
- Students grants and loan
- Study delay
- Special circumstances beyond the student’s control
- Requests to the Board of Examiners
- Requests for exemption for courses

- Contact with lecturers and (thesis) supervisors
- Contact with Central Student Administration and other departments of the faculty or university

They provide individual coaching and counselling for students with motivational problems. In case of (upcoming) study delay, students must report special circumstances (i.e. illness, practicing top level sport; doing a board year at a student association) immediately.

Please consult the study advisors on personal and study related questions or issues that might have impact on your academic success. The student counselling open office hours for short questions are daily from 12.30 – 13.30 hrs in the rooms (2.77 and 277.1) of the study advisors. Should you need more time, please make an appointment via studyadvisors-CEG@tudelft.nl.

External organisations

The group of Concrete Structures cooperates with and contributes to the following external organisations:

Betonvereniging (Concrete Association)	betonvereniging.nl/
Cement, knowledge platform concrete structures; journal	cementonline.nl
Centre for Cement&Concrete	cementenbeton.nl
The International Federation for Structural Concrete	fib-international.org/
NEN (Dutch Standardization Institute)	nen.nl
Stufib	stufib.nl

4.5 Links

Brightspace	https://brightspace.tudelft.nl
Bachelor graduation:	https://brightspace-cc.tudelft.nl/course/11406/bachelor-eindwerk---topics-bachelors-final-project-ctb3000-16--aesb3400
Concrete Structures	tudelft.nl/en/ceg/about-faculty/departments/engineering-structures/sections-labs/concrete-structures/
Exam regulation	https://www.tudelft.nl/en/student/education/courses-and-examinations/examinations
Graduation forms:	https://www.tudelft.nl/studenten/faculteiten/lr-studentenportal/onderwijs/education/forms
Graduation projects:	tudelft.nl/en/ceg/about-faculty/departments/engineering-structures/sections-labs/concrete-structures/education/master/msc-thesis/available-msc-thesis-topics/
Internship office:	tudelft.nl/en/student/study-and-career/internship-offices/
Practische studie:	practischestudie.nl
Study advisors:	tudelft.nl/index.php?id=30540
Study guide:	studyguide.tudelft.nl.
Time tables:	https://mytimetable.tudelft.nl/

U-BASE u-base.org

One World Trade Centre, made by high performance and sustainable concrete, photo by: Michael-Mahesh-PANYNJ

Back side: Faculty of Civil Engineering and Geosciences


Civil Engineering and