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1 ANNUAL REVIEW OF THE INSTITUTE

1.1 EDITORIAL AND ANNUAL REVIEW OF THE INSTITUTE

Dear friends and partners of the Institute of Concrete and Masonry Structures,
Dear ladies and gentlemen,

with the now 36th issue of "*Darmstadt Concrete*" we would like to inform you once again about the activities of our Institute in the past year and the latest developments at the "*Freunde - Verein*".

The Corona pandemic continued to dominate the work at the Institute and affected in particular the teaching. Although it was possible to create conditions in the course of the pandemic to ensure teaching at the usual high level within the framework of the online format, it is hoped that the summer semester 2022 will see a return to teaching in the presence format.
One very pleasant news is that the solid construction professorship could be filled again at the beginning of the year 2022. The new chair holder is Prof. Danièle Waldmann-Diederich. Prof. Waldmann-Diederich who was previously a professor at the University of Luxembourg. A detailed presentation of her person is given in a separate article in this issue.
A very special thank you goes to our former university president and ESA Director General Prof. Johann-Dietrich Wörner, who held the lectures on the courses Reinforced Concrete Structures I and II and Prestressed Concrete Structures in winter semester 2020/21 as well as in summer semester 2021.
A total of 11 research assistants and 3 technical employees are currently working at our Institute. Last year, we were able to recruit Dipl.-Ing. Truong Diep Hasenbank-Kriegbaum and Annika Becker, M.Sc. as new research assistants, who will support Prof. Waldmann-Diederich in redesigning the courses at the Institute and who will research on questions specific to building dynamics and masonry as part of their research and dissertation. Special mention should be made at this point of the changeover of the Master's modules in prestressed concrete construction and masonry construction to the English language from WS 2021/22, as specified by the department, in order to support the international orientation of the university.

Despite the aforementioned challenges in 2021, we are very satisfied with the achievements in both research and teaching. In economic terms, we succeeded in maintaining third-party funding income at a high level. Due to the great commitment to teaching, we also continued to receive constant allocations from the university. In addition to the successful service and research activities, the successful graduations of our graduates and the successful doctorates of our scientists in particular count among the successes achieved.
In the past year, two former doctoral students were also able to complete their doctorates at the Institute for Concrete and Masonry Structures. We congratulate them on this:

Mr. Dr.-Ing. Sebastian Hofmann	*Crack development in concrete members with basalt fibre polymer reinforcement*
Mr. Dr.-Ing. Dominik Müller	*Probabilistic Assessment of Existing Masonry Structures – The Influence of Spatially Variable Material Properties and a Bayesian Method for Determining Structure-Specific Partial Factors*

Of course, it is a special concern of ours to thank all the staff of the Institute of Concrete and Masonry Structures for their work in the past year. Without the high quality and tireless commitment with which our research assistants as well as our secretarial and laboratory staff approach their tasks and projects, the achievements and successes of our Institute in this challenging year 2021 would not have been possible. Many thanks for this!

The short reports printed below in both German and English give you a brief insight into the scientific activities of our staff. Please do not hesitate to contact us if you are interested in further information. A compilation of the scientific publications of the staff in 2021 as well as further information can be found on the Institute's homepage at:
http://www.massivbau.tu-darmstadt.de/massivbau

We would like to take this opportunity to thank all our teaching assistants and external lecturers, as without their active and competent support, it would not have been possible to maintain our teaching programme in digital form. Many thanks for their extraordinary voluntary commitment, especially during this time!

Last but not least, we would also like to thank the "Fre*unde des Instituts für Massivbau der TU Darmstadt envy.*", which supports and promotes our staff in many ways. In addition to all the members of the association, we would especially like to thank the board of directors for their great commitment.

The "*41. Darmstädter Massivbauseminar*" entitled "*Innovationen im Bauwesen durch Forschung und Entwicklung*" took place on 03.09.2021 in Darmstadt's "*Altes Schalthaus*". In addition to numerous lectures by renowned speakers from the German solid construction scene, Prof. Graubner's work and achievements were honoured at a festive evening event.

Unfortunately, due to the Corona problem, the "*Freunde-Sommerfest*" could not be held in its usual form again this year. In November, however, an autumn festival could take place, though in a somewhat smaller form, with the highly appreciated get-together in the circle of the members of the "*Freunde-Verein*".

We look forward to the year 2022 with hope and confidence. The team of the Institute wishes you a good and healthy year 2022.

Prof. Dr.-Ing. Danièle Waldmann-Diederich

Dr.-Ing. Tilo Proske

1.2 INTRODUCTION PROF. WALDMANN

The staff of the Institute of Concrete and Masonry Structures at TU Darmstadt are pleased to welcome Prof. Danièle Waldmann-Diederich as a new professor at the Institute of Concrete and Masonry Structures at the beginning of 2022.

Prof. Waldmann-Diederich’s academic career began with the study of civil engineering, which she successfully completed at TU Kaiserslautern in 1996. After her studies, she worked as a scientific assistant at TU Kaiserslautern, which she completed in 2002 with a successful dissertation on the topic of "Shear load bearing behaviour of punctually supported slab bridges". From 2000 onwards, Prof. Waldmann-Diederich worked in industry as a project manager at Eurobeton S.A.. During this time, Prof. Waldmann-Diederich also held a lectureship at the Higher Institute of Technology (IST). In 2003, she was appointed Professor of Solid Construction at the University of Luxembourg, where she last researched and taught. In addition to her diverse activities in research and teaching, Prof. Waldmann-Diederich headed the "Solid Structures (LSS)" research group from 2005 to 2022 and acted as director of the "Professional Bachelor in Engineering" degree programme at the University of Luxembourg from 2011 to 2016, as well as director of the "Civil Engineering - Megastructure Engineering with Sustainable Resources" Master's degree programme from 2016 to 2022. In the years 2016 - 2022, Prof. Waldmann-Diederich also headed the "Institute for Civil and Environmental Engineering INCEEN". In addition to numerous commitments as a member and leader of research groups, she most recently coordinated the "Thematic Task Force TTF3 Building as Material Banks" as part of the "CIRKLA European School on Materials and Metals in a Circular Economy" project of the "University of the Greater Region". In addition to numerous other nominations and successes at international awards ceremonies, Prof. Waldmann-Diederich won an "Interregional Prize for Research" in 2010. In addition, her paper on "Behaviour of Circular FRP-Steel Confined Concrete Columns Subjected to Reversed Cyclic Loads: Experimental Studies and FE Analysis" as a "highly cited paper" of the ELSEVIER Journal Construction and Building Materials.

Within the scope of her research activities, Prof. Waldmann-Diederich deals with innovative research approaches in addition to the classical topics of solid construction. In doing so, she covers research topics that concern the entire life cycle of building materials and components. These include:

- the development of novel concretes based on renewable resources;

- the development of functional demountable building components that enable later selective deconstruction in the context of a circular economy approach in the construction of new buildings, e.g. a demountable wood-concrete composite slab system or modular dry-stacked masonry blocks with the investigation of load transfer in the masonry joint;

- furthermore, following the life cycle of building materials and components, the monitoring of components and load-bearing structures for potential service life extension, such as the condition assessment of bridge structures with the specially developed DAD method, which enables damage detection and localisation on the basis of deformation measurements with the aid of photogrammetry; or also the monitoring of components for the generation of the necessary data for the preparation of selective deconstruction and potential building material reuse;

- then, recycling and selective deconstruction by analysing the recovery and recycling of building materials;

- and finally, conversion of secondary raw materials into products with attractive properties with the aim of reintegrating waste products into the life cycle, such as the substitution of cements with calcined clays, which are a waste product of the aggregate washing process.

In addition to these research projects, which often had a very application-oriented character, Prof. Waldmann-Diederich was able to advance research in the area of the further development of numerical methods for modelling the cracking behaviour of concrete at micro level. Other research projects dealt with methods in the field of Building Information Modelling (BIM) and aspects of building physics. A sign of Prof. Waldmann-Diederich's diverse research interests, also beyond the boundaries of solid construction and civil engineering, are her extensive publications in medical journals regarding the use of special plastics for orthopaedic applications. She has published a total of 63 papers in prestigious international journals. In addition, she has published four patent specifications and contributions to textbooks as well as numerous conference contributions on various topics.

Prof. Waldmann-Diederich's research at the TU Darmstadt will continue to focus on sustainability in the building industry. In doing so, the above-mentioned topics are to be further expanded. Thus, the Institute of Concrete and Masonry Structures will continue to concentrate on the topics of sustainable building materials, cycle-oriented structural design, monitoring of load-bearing structures during the utilisation phase, as well as recycling and selective deconstruction of building components and the interfaces of these topic complexes. The implementation of these research goals will be done by the development of new types of building materials based on renewable resources on the one hand and the development of new dismantlable composite components and optimisation of the use of materials for load-bearing components on the other. Then, Prof. Waldmann-Diederich aims to further develop methods for monitoring of buildings and to optimise processes for recycling and reuse of building materials. In addition, her goal is to contribute to ensuring that recycled secondary raw materials with advantageous properties are returned to the resource cycle.

With regard to the upcoming teaching activities, Mrs Waldmann-Diederich brings a lot of experience to the chair with almost 30 years as a lecturer in German, English, French and Luxembourgish. During her time as head of the civil engineering programme at the University of Luxembourg, Mrs Waldmann-Diederich was also able to gain experience in the reorganisation of study programmes.

1.3 SEMINARS AND EVENTS

1.3.1 TRAINING SEMINAR FOR STRUCTURAL ENGINEERS

As in previous years, the "*Institut für Massivbau*" invited participants to the well-known training series "*Weiterbildung für Tragwerksplanung - aus der Praxis für die Praxis*". However, the series of events was faced with special challenges this year due to the situation characterized by the corona virus. The seminars were held entirely online throughout the year and were very well received by the interested participants. For this purpose, the dates of the identical seminar series from Darmstadt and Kaiserslautern were combined. At the six seminars, a total of 24 speakers were able to present exciting reports from practice to more than 1800 participants from Darmstadt and Kaiserslautern, as well as the current state of research and standardization. In spring, current topics and news in fire protection, fastening technology and timber construction were explained. In the fall, the training series was able to provide insights into sustainable construction in structural design as well as aspects of digital planning, and shed more light on precast and modular construction. The six individual events are listed below:

26.08.2020: Fire protection

09.09.2020: Fastening technology

16.09.2020: Timber construction

15.09.2021: Digital planning

29.09.2021: Sustainable building in structural design

06.10.2021: Precast and modular construction

Despite the circumstances, the seminar event will continue next year due to the large number of participants and positive feedback. Since the coming year 2022 will also be influenced by the coronavirus, it was decided to continue to hold the spring events in an online format. For the fall, plans are being made with either presence or online formats, depending on the situation. Once again, exciting topics from research and practice await the participants. We are again trying to attract well-known speakers from industry and academia to address many structural engineers. The planned seminar contents are shown below:

02.03.2022: Technical building equipment and building physics

16.03.2022: Bridge construction

30.03.2022: Construction in existing structures

14.09.2022: Foundations and foundation structures

28.09.2022: Steel construction

12.10.2022: Earthquakes and dynamics

The latest information and the registration form can be found on the homepage of the Institute of Concrete and Masonry Structures (www.massivbau.tu-darmstadt.de) under the heading "*Events*". As contact person Mr. Christian Herget, M.Sc. is at your disposal.

1.3.2 SEMINAR FOR CONCRETE AND MASONRY

On 3 September 2021, the 41st Darmstadt Seminar for Concrete and Masonry on the topic of "*Innovationen im Bauwesen durch Forschung und Entwicklung (Innovations in Construction through Research and Development)*" took place at the "*Altes Schalthaus*" in Darmstadt. Numerous leading representatives of the research scene in solid construction were recruited for the seminar event. Within the framework of the lectures, a multitude of research topics were highlighted, which Professor Graubner also worked on during his time at the Institute for Concrete and Masonry Structures at the TU Darmstadt and which are still highly relevant today. The variety of technical contributions ranged from classic solid construction topics of design and construction as well as research into new and recycled materials in masonry and concrete construction to new regulations in the field of concrete technology and research into sustainability and life cycle assessment.

Figure 1-1: Prof. Graubner among the speakers at the 41st Darmstadt Seminar for Concrete and Masonry and the board of the „Freunde Verein"

Professor Graubner said goodbye to his friends, former colleagues and companions from Darmstadt at a festive evening event that took place after the seminar.

1.3.3 DARMSTADT DAYS FOR PREFABRICATED CONCRETE ELEMENTS

Also in 2021, the "*Darmstadt Days for Prefabricated Concrete*" were planned in cooperation with the "*Fachvereinigung Deutscher Betonfertigteilbau (FDB)*" (Association of German Prefabricated Concrete Builders) and the "*InformationsZentrum Beton*" (Concrete Information Centre). Due to corona the seminar days took place completely in online format. Nevertheless, with 174 participants from engineering practice and around 40 students, the number of participants was higher than ever in 14 years before.

On 7 mornings, speakers from science and practice presented numerous lectures on the topic of precast construction. In addition to current trends, such as innovative components with carbon reinforcement or digital planning with BIM, the focus was on the fundamentals and special features of precast construction. This also included prestressed components, fire protection and connections. The broad range of topics offered participants both, an introduction to precast construction as well as the opportunity to deepen their knowledge. Thanks to the chat function, questions could be asked after each lecture, so that dialogue and communication were not neglected.

In addition to engineers from practice, the event was also aimed towards students, who dealt with the design of precast concrete elements in depth in exercises on a separate "*student day*". In addition to the 7 seminar days, a further morning was offered for students only, during which the planning atlas for structural engineering and the topic of production, transport and assembly of precast elements were presented. Thus, the lecture "*Precast Structures*", which takes place within the framework of the Darmstadt Precast Concrete Days, can be meaningfully integrated into a structural engineering course of study.

In the coming year 2022, the "*Darmstadt Days for Prefabricated Concrete*" will unfortunately not be able to take place in the spring due to the new appointment of the professorship. However, all those involved are endeavouring to ensure that the event will take place again either in autumn 2022 or in spring 2023 at the latest.

Current information can be found on the homepage of the Institute for Concrete and Masonry Structures (www.massivbau.tu-darmstadt.de) under the heading "*Events*". In case of questions, please do not hesitate to contact Ms. Anna Müller M.Sc.

1.4 PERSONAL MATTERS

Since September the 1th 2021, Mrs **Truong Diep Hasenbank-Kriegbaum, Dipl.-Ing.,** has been teaching and researching at the Institute of Concrete and Masonry Structures at TU Darmstadt and is currently in charge of the course Prestressed Concrete Structures and Applied Structural Dynamics as course assistant.

She studied Civil engineering at the TU Darmstadt from 2003 to 2010, specialising in solid construction, geotechnics and construction management. Mrs Hasenbank-Kriegbaum completed her studies with her thesis at the Institute for Concrete and Masonry Structures with a focus on structural dynamics on the topic of "*Investigation of a water-filled tank under earthquake loading*".

After completing her studies, Mrs Hasenbank-Kriegbaum worked as an engineer at the Wölfel engineering office in Höchberg near Würzburg in the plant construction department. Her main activity was the analysis of structures and plant components, mainly in industrial and power plant construction, under the stress of operational loads as well as dynamic loads, especially earthquake loads, using different static and dynamic calculation methods. Among other things, she carried out investigations on the stability of structural plant components using the finite element method. After 2 years, she changed to Hochtief Consult IKS as a structural dynamic engineer in the earthquake, structural dynamics and special projects department. Her tasks included dynamic calculations of structures, piping systems, vessel stacks and plant components for the load cases earthquake, explosion and wind; the determination of floor response spectra with detailed consideration of the soil-structure interaction; probabilistic and deterministic seismic analyses of existing nuclear power plants; non-linear time history analyses and push-over calculations of buildings and cooling towers under wind, earthquake and explosion; and the determination of accident-related crash probabilities of an aircraft for the design of a nuclear power plant.

Ms. Annika Becker, M.Sc. has been working at the Institute of Concrete and Masonry Structures since October the 16th, 2021. She studied Civil engineering at TU Darmstadt from 2014 to 2019, majoring in solid construction, steel construction and structural analysis. During her master's studies, Ms. Becker worked for two years as a student trainee in the technical office at Donges SteelTec in Darmstadt. Ms. Becker completed her studies with a thesis at the Institute of Concrete and Masonry Structures on the load-bearing and deformation behavior of concrete components subjected to bending stresses with carbon-fiber reinforced polymer reinforcement. She evaluated bending tests using digital image correlation and conventional measurement techniques and compared the agreement of the test results with the calculation results from the design formulas currently available in literature. After completing her studies, Ms. Becker worked as a structural engineer at Krebs und Kiefer in Darmstadt. Her main activities were structural design and structural examination of buildings in solid construction. At the Institute of Concrete and Masonry Structures, Ms. Becker is in charge of the course Reinforced Concrete Construction II.

1.5 AWARDS

1.5.1 AWARD OF THE „*FREUNDE-VEREIN*“

Unfortunately, the sponsorship prize of the "*Freunde Verein*" could not be awarded this year. The general meeting of the Friends of the Institute of Concrete and Masonry Structures took place in 2021 with a concluding autumn festival. The event was planned at very short notice due to some uncertainties regarding the Corona pandemic. The board agreed to offer a double prize in 2022, provided that a general meeting, at which the award ceremony usually takes place, is permitted to be present.

1.5.2 VERBAND BAUGEWERBLICHER UNTERNEHMER AWARD

In October 2021, the "*Verband Baugewerblicher Unternehmer Hessen e. V.*" awarded prizes to students and graduates for their theses and dissertations. The three best submissions in each of the four different categories were awarded prizes. In the field of Civil engineering, the Institute for Concrete and Masonry Structures took first and third place. Ms Celine Willecke, M.Sc. won first place with her Master's thesis on "*Investigation of the load-bearing behaviour of bridge structures with fibre composite plastic reinforcement*", supervised by Mr Dominik Hiesch, M.Sc. Third place was won by Ms Nicole Rösser, B.Sc. for her bachelor thesis entitled "*Low clinker cements with limestone and calcined clay - influence of cement composition and water-cement ratio on selected mortar properties*", supervised by Ms Anna Müller, M.Sc.

1.5.3 DRESSLER BAU AWARD

Due to postponements in connection with the Corona pandemic, the Dreßler-Bau Prize for outstanding bachelor theses in the fields of solid construction and construction management for 2021 will not be awarded until the spring of next year at the "*Ausgezeichnet*" event. This time, Nicole Rösser, B.Sc. and Sebastian Ruß, B.Sc., two students who completed their Bachelor's thesis at the Institute of Concrete and Masonry Structures, were nominated for the prize, which is endowed with 1,500 € per winner. The students were supervised by Ms Anna Müller, M.Sc. and Mr Lukas Bujotzek, M.Sc respectively.

We would like to take this opportunity to congratulate them on their nomination and wish them every success for the award ceremony at the beginning of this year!

1.6 ACKNOWLEDGEMENTS

Without the support of the following organisations we would not have been able to perform our work in research and education in its entirety during the past year:

Apleona HSG GmbH
Arbeitsgemeinschaft industrieller Forschungsvereinigungen „Otto von Guericke“ e.V.
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Bundesministerium für Bildung und Forschung
Bundesministerium für Wirtschaft und Energie (BMWi)
Bundesministerium des Innern, für Bau und Heimat
Bundesverband der Deutschen Ziegelindustrie
Bundesverband der Kalksandsteinindustrie e.V.
Bundesverband Porenbetonindustrie e.V.
Bundesverband Deutsche Beton- und Fertigteilindustrie e.V.
Bundesverband Leichtbeton e.V.
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Deutsches Institut für Bautechnik
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Dyckerhoff GmbH
Empa Dübendorf
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Hochtief AG

HSE Technik GmbH
Implenia
InformationsZentrum Beton GmbH
Ingenieurbüro Krebs und Kiefer
Inno-Test-Lab GmbH
Institut Wohnen und Umwelt
Klimaleichtblock GmbH
König und Heunisch Planungsgesellschaft mbH & Co KG
LCEE Life Cycle Engineering Experts GmbH
Liapor GmbH & Co.
LohrElement GmbH
mako GmbH & Co. KG Schalungstechnik
MAPEI Betontechnik GmbH
Max Bögl Bauunternehmen GmbH
MEVA Schalungssysteme GmbH
OPTERRA Karsdorf GmbH
pakon AG
Peri GmbH
Projektträger Jülich (PtJ)
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sh minerals GmbH
solidian GmbH
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VHT Versuchsanstalt für Holz- und Trockenbau GmbH
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We want to express our gratitude for this support and hope for a successful cooperation in the future.

In teaching, a support by experts from the private sector, the industry, administration and organisations is necessary and highly appreciated, especially in order to include all practical aspects of civil engineering. For their personal commitment as visiting lecturers at our Institute we would like to thank the following persons:

Dr.-Ing. Markus Spengler	Applied Structural Dynamics
Dipl.-Ing. Thomas Heß	Building Service Engineering I + II
Dr.-Ing. Carmen Mielecke	Strategic Facility Management & Sustainable Design
Dr.-Ing. Gert Riegel	Strategic Facility Management & Sustainable Design
Prof. Dr.-Ing. Georg Geldmacher	Concrete Bridges and Falsework
Dr.-Ing. Valentin Förster	Masonry and special topics of concrete structures

Furthermore, we would like to thank the following persons for their lectures as well as for their commitment.

Applied Structural Dynamics
Dr.-Ing. Herbert Duda

Prefabricated Concrete Constructions
Dipl.-Ing. Mathias Tillmann
Dipl.-Ing. Christian Goldbrunner
Dipl.-Ing. Werner Hochrein
Roland Klein-Holte
Dr.-Ing. Larissa Krieger
Dr.-Ing. Tanja Skottke
Dr.-Ing. Johannes Furche
Prof. Dipl.-Ing. Dominik Wirtgen
Dipl.-Ing. Martin Hierl
Dipl.-Ing. Elisabeth Hierlein
Judith Pütz-Kurth
Dipl.-Wirt.-Ing. Peter Schermuly
Friedhard Ströhmann
Dipl.-Ing. Jörg Burkhardt
Dr.-Ing. Diethelm Bosold
Dipl.-Ing. Erwin Scholz

Concrete Bridges and Falsework
Dr.-Ing. Gerhard Zehetmaier
Dr.-Ing. Stefan Kempf
Dr.-Ing. Jochen Zeier
Dr.-Ing. Jaroslav Kohoutek

Prestressed Concrete Structures
Dr.-Ing. Stefan Daus

Strategic Facility Management & Sustainable Design
Dr.-Ing. Torsten Mielecke
Dr.-Ing. Sebastian Pohl
Dr.-Ing. Martina Lohmeier

Building Service Engineering
Dipl.-Ing. Patrick Bös
Ing. Marcel Jansen
Dr.-Ing. Leif Pallmer
Dipl.-Ing. Olaf Pielke
Verena Schön M.Sc.
Prof. Dr.-Ing. Benjamin von Wolf-Zdekauer
Dr.-Ing. Claudia Weißmann

Masonry and special topics of concrete structures
Dipl.-Ing. Georg Flassenberg
Dr. Dieter Figge
Sebastian Warken

1.7 PUBLICATIONS

Selected papers and book chapters:

Brinkmann, M.; Armenat, J.: Vertikale Begrünung mit UNIKA-Pflanzsteinen - Hintergründe zur Anwendung, Bemessung und Konstruktion, In: Mauerwerk 26, Heft 1, 2022, Ernst & Sohn, Berlin, DOI: https://doi.org/10.1002/dama.202100011.

Proske, T.; Scheich, C.; Rezvani, M.: Pressure-Dependent Shear Behavior of Fresh Concrete, In: ACI MATERIALS JOURNAL, Issue 20-388, 2021, American Concrete Institute.

Herget, C.; Müller, A.; Proske, T.; Rezvani, M.; Graubner, C.-A.: Kalksteinmehl als Betonzusatzstoff – Vorschlag für die Anrechenbarkeit auf den Zementgehalt und Potenzial zur CO2-Reduktion im Betonbau, In: Beton- und Stahlbetonbau, Heft 116, 2022, Wiley, DOI: https://doi.org/10.1002/best.202100073 .

Bujotzek, L.; Hiesch, D.; El Ghadioui, R.; Proske, T.: Material Properties of Fibre Reinforced Polymer (FRP) Reinforcement in Compression – A Review, In: Concrete Structures: New Trends for Eco-Efficiency and Performance, 14.-16. Juni 2021, Fédération Internationale du Béton (fib) – International Federation for Structural Concrete, Lissabon, S. 897-906, ISBN: 978-2-940643-08-0."

El Ghadioui, R.; Hiesch, D.; Bujotzek, L.; Proske, T.; Graubner, C.-A.: Structural behaviour of CFRP reinforced concrete members under monotonic and cyclic long-term loading, In: Materials and Structures, Vol. 54, 2021 (137), S. 1-18, DOI: https://doi.org/10.1617/s11527-021-01728-4.

Graubner, C.-A.; Brinkmann, M.; Förster, V.: Effiziente Bemessung von Leichtbetonmauerwerk nach neuesten normativen Regelungen, In: BFT International, Ausgabe 02/2021, Bauverlag BV GmbH, Gütersloh.

Sykora, M.; Diamantidis, D.; Müller, D.; Helder, S.: A practical guide on the quantification of value of information gained by structural health monitoring and application to historic masonry structures, In: Structure and Infrastructure Engineering, Taylor & Francis, DOI: https://doi.org/10.1080/15732479.2020.1857793.

Müller, D.; Proske, T.; Graubner, C.-A.: Stochastic Simulation of Clay Brick Masonry Walls with Spatially Variable Material Properties, In: 18th International Probabilistic Workshop, 12.-14. Mai 2021, Springer, Guimarães, S. 779-791, ISBN: 978-3-030-73615-6, DOI: https://doi.org/10.1007/978-3-030-73616-3_60.

Müller, D.; Graubner, C.-A.: Assessment of Masonry Compressive Strength in Existing Structures Using a Bayesian Method, In: ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering, Vol. 7, 2021, DOI: https://doi.org/10.1061/AJRUA6.0001113.

Selected presentations

Graubner, C.-A.; Brinkmann, M.: Mauerwerk - Effiziente Bemessung nach DIN EN 1996-1-1 und DIN EN 1996-3, 41. Darmstädter Massivbauseminar, Darmstadt, 03.09.2021.

Bujotzek, L.; Hiesch, D.; El Ghadioui R.; Proske, T.: Material properties of fibre reinforced polymer (FRP) reinforcement in compression – A review, fib Symposium 2021, Lisbon, 14.-16.06.2021

Graubner, C.-A.; Brinkmann, M.; Förster, V.: Effiziente Bemessung von Leichtbetonmauerwerk nach neuesten normativen Regelungen, 65. BetonTage, Neu-Ulm, 23.02.2021.

1.8 STUDENT FINAL THESES AT THE INSTITUTE IN 2021

Title of final thesis	Supervisor	Type of thesis
Rissbreitenbegrenzung massiger Bauteile aus Stahlbeton	Klein	Bachelor thesis
Rotationskapazität von bewehrten Betonbauteilen – Mechanische Grundlagen, Rechenmodelle und Einflussfaktoren vor dem Hintergrund neuartiger Bewehrungsmaterialien	Klein	Bachelor thesis
Lehm - Ein traditionsreicher Baustoff	Brinkmann	Bachelor thesis
Klinkerreduzierter Betone mit Kalksteinmehl und calciniertem Ton – Einfluss der Zusammensetzung und des w/z-Wertes auf ausgewählte Eigenschaften	Müller, A. L.	Bachelor thesis
Untersuchungen zur Feuchteabhängigkeit der Festigkeits- und Verformungseigenschaften von Lehmsteinen	Brinkmann	Bachelor thesis
Anrechenbarkeit von Kalksteinmehl auf das Schwindverhalten von Zementstein	Herget	Bachelor thesis
Verwendung von Klimadatensätzen für die Energiebedarfsermittlung von Gebäuden	Koert	Bachelor thesis
Untersuchung des Verbundverhaltens von Faserverbundkunststoffbewehrungen in Beton	Hiesch	Bachelor thesis
Untersuchungen zum Tragverhalten von Betonbauteilen mit Bewehrung aus Faserverbundkunststoffen (FVK) unter Druckbeanspruchung	Bujotzek	Bachelor thesis
Tragverhalten von Bewehrung aus Faserverbundkunststoffen (FVK) unter dauerhafter Druckbeanspruchung	Bujotzek	Bachelor thesis
Untersuchung zum Mindestzementgehalt – Auswirkung der Absenkung des Zementgehaltes auf ausgewählte Betoneigenschaften	Müller, A. L.	Bachelor thesis
Anwendung des Nennkrümmungsverfahrens auf Betonstützen mit FVK-Bewehrung	Bujotzek	Bachelor thesis
Untersuchungen zur Wirtschaftlichkeit des Einsatzes von Faserverbundkunststoffen (FVK) als Biegedruckbewehrung	Bujotzek	Bachelor thesis
Untersuchungen zur Feuchteabhängigkeit der Festigkeits- und Verformungseigenschaften von Lehmmauermörtel	Brinkmann	Bachelor thesis
Bemessung eines integralen Brückenbauwerks in Carbonbetonbauweise unter zyklischer Lastbeanspruchung	Bujotzek	Bachelor thesis
Verfahren zur plastischen Schnittgrößenermittlung im konstruktiven Betonbau vor dem Hintergrund neuartiger Bewehrungsmaterialien	Klein	Bachelor thesis
Entwicklung eines Modellierungsansatzes zur Vorhersage der reversiblen und irreversiblen Schwindverformungen von Zementstein	Herget	Bachelor thesis

Title of final thesis	Supervisor	Type of thesis
Untersuchungen zum Einfluss des Zementgehaltes auf die Frisch- und Festbetoneigenschaften von Betonmischungen mit optimierter Korngrößenverteilung	Müller, A. L	Bachelor thesis
Plastische Berechnungsmethoden im konstruktiven Betonbau vor dem Hintergrund neuartiger Bewehrungsmaterialien	Klein	Bachelor thesis
Analyse des Einflusses verschiedener Eingangsparameter auf die dynamische Energiebedarfsrechnung von Gebäuden	Koert	Master thesis
Verformungsverhalten von Betonbauteilen mit vorgespannter Faserverbundkunststoffbewehrung	Hiesch	Master thesis
Untersuchung des Materialverhaltens von Faserverbundkunst-stoffen unter zyklischer Beanspruchung	Bujotzek	Master thesis
Untersuchung der Dauerhaftigkeit und mechanischen Eigen-schaften von Multikompositzementen mit calciniertem Ton und Kalksteinmehl	Müller, A.L.	Master thesis
Weiterentwicklung der Ökobilanzierung von Gebäuden unter Berücksichtigung unsicherer zukünftiger Rahmenbedingungen	Koert	Master thesis
Verformungsverhalten von Zementstein unter zyklischer Tem-peratur- und Feuchtebeanspruchung	Herget	Master thesis
Untersuchung des Tragverhaltens von Brückenbauwerken mit Faserverbundkunststoffbewehrung	Hiesch	Master thesis
Untersuchungen zum Lastumlagerungsvermögen druckbean-spruchter Mauerwerkswände	Müller, D.	Master thesis
Einfluss des Umgebungsklimas auf die Festigkeits- und Verfor-mungseigenschaften druckbeanspruchten Lehmmauerwerks	Brinkmann	Master thesis
Hygrothermische Analyse von Lehmmauerwerkswänden mittels numerischer Simulation	Brinkmann	Master thesis
Untersuchung der notwendigen technischen Rahmenbedingun-gen für den effizienten Einsatz von Wärmepumpen in moderni-sierten Mehrfamilienhäusern	Müller, A.	Master thesis
Nichtmetallische Bewehrung für druckbeanspruchte Betonbau-teile – experimentelle und theoretische Untersuchungen	Bujotzek	Master thesis
Experimentelle Untersuchung zur Rotationskapazität von FVK-bewehrten Bauteilen	Klein	Master thesis
Entwicklung einer Methodik zur Generierung von Erzeugungs-lastprofilen von Solarthermieanlagen und deren Einbindung in bestehende Anlagen und Gebäudemodelle	Koert	Master thesis
Untersuchungen zur Zuverlässigkeit FVK-bewehrter Betonkon-struktionen unter zentrischer und exzentrischer Druckbeanspru-chung	Bujotzek	Master thesis

Title of final thesis	**Supervisor**	**Type of thesis**
Betonbauteile mit vorgespannter Faserverbundkunststoffbewehrung im sofortigen Verbund unter dauerhafter Lastbeanspruchung	Hiesch	Master thesis
Entwicklung einer Planungshilfe zur Auslegung der elektrischen Betriebsmittel in Gebäuden	Koert	Master thesis
Bemessung schwingungsanfälliger Stahlbeton-Tragstrukturen mithilfe dreidimensionaler Finite-Elemente-Gebäudemodelle	Klein	Master thesis
Untersuchung des Verformungsverhalten von Betonbauteilen mit vorgespannter Faserverbundkunststoffbewehrung	Hiesch	Master thesis
Untersuchungen zum Feuchtegehalt tragender Lehmmauerwerkskonstruktionen im Wohnungsbau	Brinkmann	Master thesis
Numerische Untersuchung des Tragverhaltens von Betonbauteilen mit vorgespannter Faserverbundkunststoffbewehrung	Hiesch	Master thesis
Numerische Modellierung von im Grundriss gekrümmten Spannbetonbrücken	Hiesch	Master thesis
Betonbauteile mit vorgespannter Bewehrung aus Faserverbundkunststoffen im sofortigen Verbund - Theoretische und experimentelle Untersuchungen	Hiesch	Master thesis
Untersuchungen zur Tragfähigkeit von Ausfachungswänden aus unbewehrtem Mauerwerk	Brinkmann	Master thesis
Untersuchung des Einflusses ausgewählter Parameter auf die Materialeigenschaften nichtmetallischer Bewehrung unter Druckbeanspruchung	Bujotzek	Master thesis
Tragverhalten statisch unbestimmt gelagerter Betonbalken mit Stahl- und FVK-Bewehrung	Klein	Master thesis

2 DARMSTADT CONCRETE 2021: ARTICLES

2.1 FIELDS OF RESEARCH AT THE INSTITUTE

Our research objectives are based on the common idea of constructing our buildings safer, more durable, more economical and more environmentally friendly. For this reason, the Institute of Concrete and Masonry Structures deals with a wide variety of topics within six research areas.

Figure 2-1: Research Fields at the Institute of Concrete and Masonry Structures

The scientific articles in this journal are divided into the following categories:

- Construction and Design
  Construction and Design, Masonry, Risk and Safety
- Mineral and ecological building materials
- Energy and Sustainability
  Energy Research, Sustainable Design

The illustrations in the scientific papers are renumbered in each article.

2.1 RESEARCH FIELD: CONSTRUCTION AND DESIGN

Research Field: Construction and Design

The research area "*Construction and Design*" takes a central role at the Institute of Concrete and Masonry Structures. It includes all questions concerning the planning and design of concrete and masonry structures. The focus is on innovations in the design and construction of reinforced concrete and prestressed concrete members that meet the high requirements of modern buildings.

Research Field: Masonry

Increased demands on modern buildings in terms of economy and comfort as well as the great economic importance of masonry as a traditional building material require sustainable innovations for this type of construction. Increased requirements with regard to heat, sound and fire protection, the need for rationalisation and improved material properties lead to optimised masonry constructions, which pose a wide variety of challenges to practical research in the field. In this context, new products are scientifically accompanied in order to be taken into account in masonry standardisation. In addition, improved dimensioning methods are being developed which make optimum use of the potential of masonry and thus increase its economic efficiency.

Research Field: Risk and Safety

Safety and reliability are among the most important characteristics of structural and technical systems. In this context, the concept of safety demands the absence of dangers to the life and limb of people in the direct vicinity of buildings or technical systems.

For several years, the Institute of Concrete and Masonry Structures has been conducting intensive research work in the field of safety and reliability of structural systems. The research projects to be carried out deal with the modelling of actions and resistances, the calibration of safety and combination factors as well as the consideration of extraordinary actions in structural engineering.

INFLUENCE OF HUMIDITY ON THE STRENGTH AND DEFORMATION CHARACTERISTICSOF EARTH MASONRY

Maximilian Brinkmann

For the design of masonry walls under compression, knowledge of their strength and deformation characteristics is essential. In contrast to common masonry materials, the compressive strength and modulus of elasticity of earth masonry are strongly influenced by ambient humidity. To investigate the influence of varying humidities on the load-bearing capacity of earth masonry, experimental tests on stack-bonded prisms made of earth bricks and earth mortar (cf. Figure 2-2) under different climatic conditions are carried out at the Institute for Concrete and Masonry Structures as part of a research project funded by the Bundesinstitut für Bau-, Stadt- und Raumforschung (BBSR)

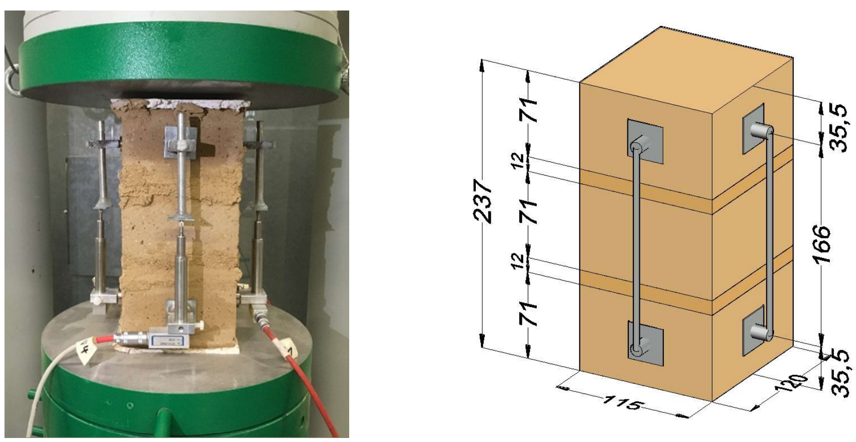

Figure 2-2: *Stack-bonded prisms made of earth bricks and earth mortar including vertical displacement transducers (dimensions in mm)*

The test series comprised the determination of the strength and deformation characteristics after conditioning the specimens to mass constancy at seven different relative humidities φ in combination with the normative reference temperature of $\theta = 23$ °C. Furthermore, some tests were carried out at constant relative humidity and different temperatures.

The evaluation of the test results showed that changes in the temperature within the range relevant for construction practice (10 °C $\leq \theta \leq$ 40 °C) do not significantly influence the strength and deformation characteristics of earth masonry. On the other hand, changes in humidity have a significant effect on the material characteristics of earth masonry, as shown in Figure 2-3 for the compressive strength and the modulus of elasticity.

Due to the test results, a linear correlation between the compressive strength and the humidity can be derived over the entire range of hygroscopic material moisture content. This dependence can also be transferred to the modulus of elasticity for an increased humidity of $\varphi > 40$ %. Since lower humidities do not usually occur over longer periods, minor deviations from the linear correlation are negligible in this case. In the future, the presented test results will be used for the development of a new national standard for the design of load-bearing earth masonry walls.

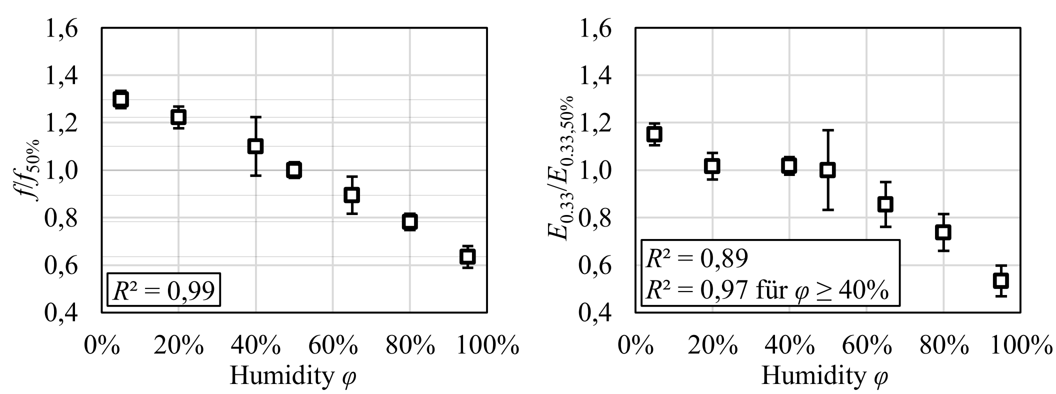

Figure 2-3: Normalized mean values of compressive strength and modulus of elasticity of earth masonry depending on the humidity φ

EXPERIMENTAL INVESTIGATIONS TO DETERMINE THE STRENGTH AND DEFORMATION PROPERTIES OF FRP REINFORCEMENT UNDER COMPRESSIVE LOADING

Lukas Bujotzek

Research and development on fibre reinforced plastic (FRP) reinforcement for concrete construction is predominantly concerned with its application under tensile loading. The contribution of such reinforcement in compression is currently not permitted by leading international standards.

However, current research projects show that neglecting the load-bearing component in the design of concrete members subject to compressive stress can lead to inefficient results. As a result of the wide range of results on material properties of FRP reinforcement, which could be determined within the scope of an extensive literature study, it is necessary to expand the test basis on the aid of a suitable test programme and set-up for the purpose of further research into this topic. Therefore, more than 100 tests for the experimental determination of compressive strength and modulus of elasticity in compression were carried out at the Institute of Concrete and Masonry Structures at TU Darmstadt last year. The free length of the specimens was chosen after careful consideration to be six times the bar diameter (6 · Ø). The loads are applied to the transversely anisotropic material with the aid of steel sleeves cast in concrete, cf. Figure 2-4. Strains are recorded at two points during the tests with the aid of an extensometer.

Figure 2-4: Used materials, test specimens, instrumentation and test set-up

Within the scope of the test programme, reinforcement made of three different fibre materials (glass (GFRP), basalt (BFRP), carbon (CFRP)), three different manufacturers and different bar diameters were tested. For each of these characteristics, a sample of n = 10 tests was evaluated. The results of the tests are summarised in the following figure.

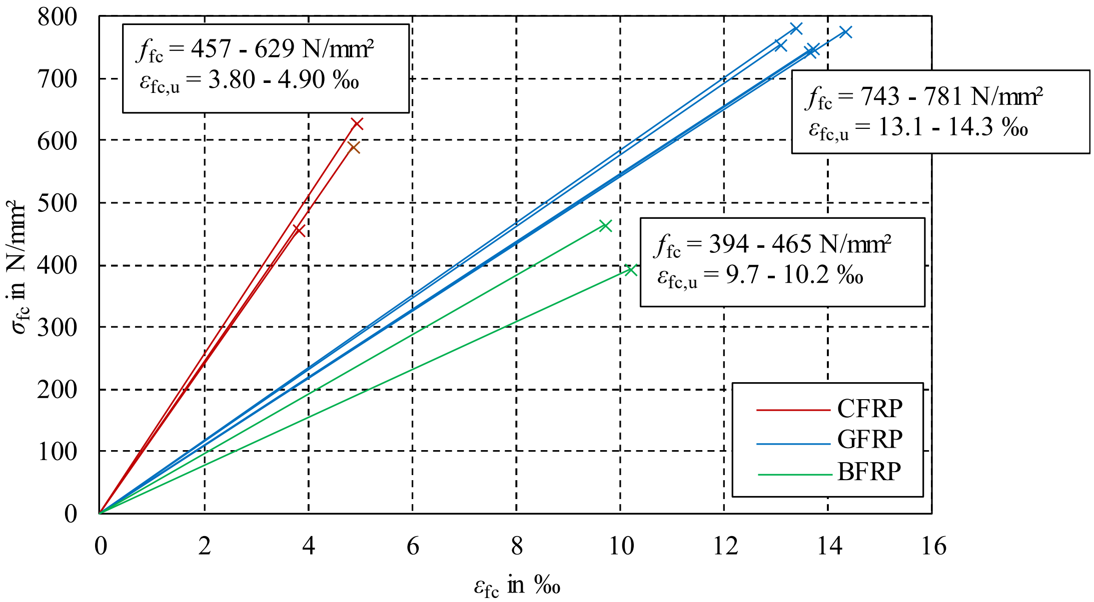

Figure 2-5: Ultimate strengths and strains of the reinforcement types investigated

It becomes apparent that the material behaviour under compressive stress displays the linear-elastic behaviour typical for FRP. An evaluation of the data shows that the modulus of elasticity of all tested materials under compressive stress corresponds to that in tension. In contrast to the modulus of elasticity, the results in Figure 2-5 show clear differences between the materials in terms of ultimate strain and strength. Due to the high stiffness and low strength of CFRP, the ultimate strain is low and there is also a high degree of scatter. It can therefore be assumed that for this material it cannot be stated with adequate confidence that the design value of the ultimate strain is greater than the ultimate compressive strain of the concrete. In contrast, the results for GFRP show the highest strengths. The reason for this is seen in the high diameter of the individual fibres for glass fibres, which leads to a higher buckling load of the single fibres on a microscopic level. Furthermore, the scatter range of this type of fibre is low, independent of bar diameter and manufacturer, which confirms the reliability of the results. The results regarding the BFRP reinforcement are of minor interest for further investigations, since neither a favourable stiffness nor high strengths are achieved and the scatter is also large.

DEFORMATION BEHAVIOUR OF PRESTRESSED CONCRETE MEMBERS WITH GFRP TENDONS

Dominik Hiesch

The use of reinforcement made of fibre-reinforced plastics (FRP) enables the construction of slender and durable concrete components due to the high tensile strength and the good corrosion resistance of the reinforcement. However, the usually low moduli of elasticity of common FRP reinforcement bars made of glass or carbon fibres lead to significantly larger deformations of conventionally reinforced members in the cracked state II due to the greatly reduced bending stiffness compared to steel-reinforced concrete members. To counteract this problem and to use the high tensile strength of the FRP tendons more efficiently, the reinforcement can be prestressed. In addition to the verification of the deformation in the serviceability limit state, where the deformation has to be limited to 1/250 of the span according to Eurocode 2 [1], the deformation in the ultimate limit state must also be examined when using prestressed FRP tendons. Due to the linear-elastic material behaviour of the FRP reinforcement without any yielding capacity, the usual ductility criteria regarding a sufficiently early notice of failure cannot be fulfilled by considering the material side. Instead, this can be taken into account at the member level, by ensuring sufficient deformability. Consequently, a minimum value of the component deformations shall be defined for the design load case. For this purpose, Osman-Letelier et al. [2] propose a value of 1/100 of the span at which a visual failure indication is already recognisable.

Figure 2-6: Manufacturing and testing of a member with prestressed GFRP tendons

Within the framework of an experimental investigation the deformation behaviour of prestressed concrete members with GFRP tendons was examined in a four-point bending test, as shown in Figure 2-6 for member V-1. Within the computational verification of the test results, a calculation model is used, that captures the stiffness development of the prestressed members in detail and thus approximates the occurring deformations as best as possible. Figure 2 shows an example of the good agreement between test and calculation results for the examined member V-1. The section limits shown in Figure 2-7 are 1/250 of the span for the service load case and 1/100 of the span for the design load case, following the literature mentioned above.

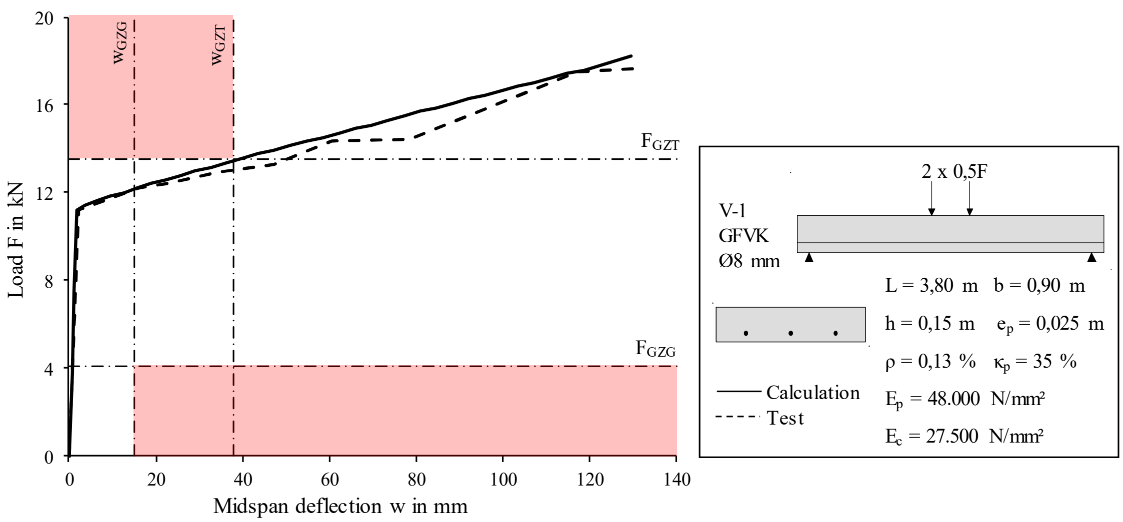

Figure 2-7: Load-deflection relation and boundary conditions of component V-1

Based on this calculation model and an extended experimental study with a variation of the reinforcement ratio ρ, the prestressing ratio κ_p and the tendon eccentricity e_p, the proposed deformation limits are to be verified for a wide range of applications and an economically and technically optimised design for prestressed concrete members with FRP tendons will be derived.

[1] DIN EN 1992-1-1/NA. Eurocode 2: Bemessung und Konstruktion von Stahlbeton- und Spannbetontragwerken – Teil 1-1: Allgemeine Bemessungsregeln und Regeln für den Hochbau; DIN Deutsches Institut für Normung e. V.

[2] Osman-Letelier, J. P.; Hückler, A.; Schlaich, M. (2021) Dünnwandige Fertigteile aus vorgespanntem Carbonbeton. Beton- und Stahlbetonbau. https://doi.org/10.1002/best.202100019

DESIGN APPROACH FOR THE CALCLUATION OF CRACK WIDTHS IN BFRP REINFORCED CONCRETE MEMBERS

Sebastian Hofmann

The use of alternative reinforcement materials, such as fibre reinforced polymers (FRP) is part of current research projects. The reinforcement investigated in this article is made of basalt fibre reinforced polymers (BFRP) and has a helically wrapped and sand coated surface profiling. The mechanical properties differ strongly compared to conventional reinforcement steel. Furthermore, due to the material properties, the surface is much softer and smoother than a ribbed steel rebar. For this reason, the bond behaviour of theses reinforcement bars in concrete members is different compared to conventional steel reinforced concrete.

The calculation of the crack widths in reinforced concrete members depends on the mean bond stresses between concrete and reinforcement, which is introduced into the component as a result of the tensile reinforcement stress. In the design model according to DIN EN 1992-1-1, a constant ratio of the mean bond stress and the concrete tensile strength of $\tau_{bm} = 2.25 \cdot f_{ctm}$ is given for reinforcement steel. For BFRP reinforcement, however, there is no constant relationship between the bond stress and the concrete tensile strength [1].

To calculate the maximum crack width, the maximum crack spacing $s_{cr,max,d}$ is necessary, which can be calculated for the helically wrapped and sand coated BFRP reinforcement as follows:

$$s_{cr,max,d} = 2 \cdot k \left[l_{t,max} \leq l_t \right]$$
$$= 0,604 \cdot k \left[\sqrt{\frac{f_{ctm}}{\rho_{f,eff}}} \cdot \left(\frac{E_f}{\left(1 + \alpha_f \cdot \rho_{f,eff}\right)} \right)^{\frac{1}{4}} \cdot \left(\frac{Ø_f}{\sqrt{f_{cm}}} \right)^{\frac{3}{4}} \leq \sqrt{\sigma_{f2}} \cdot E_f^{\frac{1}{4}} \cdot \left(\frac{Ø_f}{\sqrt{f_{cm}} \cdot \left(1 + \alpha_f \cdot \rho_{f,eff}\right)} \right)^{\frac{3}{4}} \right] \quad (1)$$

$$k = \sqrt{\frac{48}{f_{cm}}} \quad (2)$$

If the maximum crack distance is known, the maximum crack width according to Eq. (3) can be calculated in the same way as for steel reinforced concrete members. However, the reinforcement strain at the cracked section has to be verified. An equation to check the strains can be taken from DIN EN 1992-1-1 / NA and is in the second term of Eq. (4) taken into account.

Thus, using the maximum crack spacing from Eq. (1) multiplied by the difference of the reinforcement and concrete strains $\Delta\varepsilon$, the maximum crack width $w_{cr,max,d}$ can then be determined.

$$w_{\mathrm{cr,max,d}} = s_{\mathrm{cr,max,d}} \cdot \Delta\varepsilon \tag{3}$$

$$\Delta\varepsilon = \left(\varepsilon_{\mathrm{fm}} - \varepsilon_{\mathrm{cm}}\right) = \frac{1}{E_{\mathrm{f}}}\left(\sigma_{\mathrm{f2}} - \beta_t \cdot \frac{f_{\mathrm{ct,eff}}}{\rho_{\mathrm{f,eff}}} \cdot \left(1 + \alpha_{\mathrm{f}} \cdot \rho_{\mathrm{f,eff}}\right)\right) \geq \left(1 - \beta_{\mathrm{t}}\right) \cdot \frac{\sigma_{\mathrm{f2}}}{E_{\mathrm{f}}} \tag{4}$$

With:

E_f	Young's Modulus of reinforcement;	σ_{f2}	reinforcement stress at cracked stage
$\rho_{f,eff}$	effective reinforcement ratio;	α_f	E_f / E_c

β_t Tension stiffening factor of the BFRP-reinforcement (β_t = 0,57 for short term loading and $\beta_{t,\infty}$ = 0,38 for permanent loading)

Taking the material parameters of the reinforcement and a maximum acceptable crack width of $w_{cr,max}$ = 0.4 mm, an indirect dimensioning diagram as a function of the reinforcement stress and the used bar diameter (see Figure 2-8) is created using Eq. (3). This diagram enables a simple and efficient dimensioning to limit the crack width.

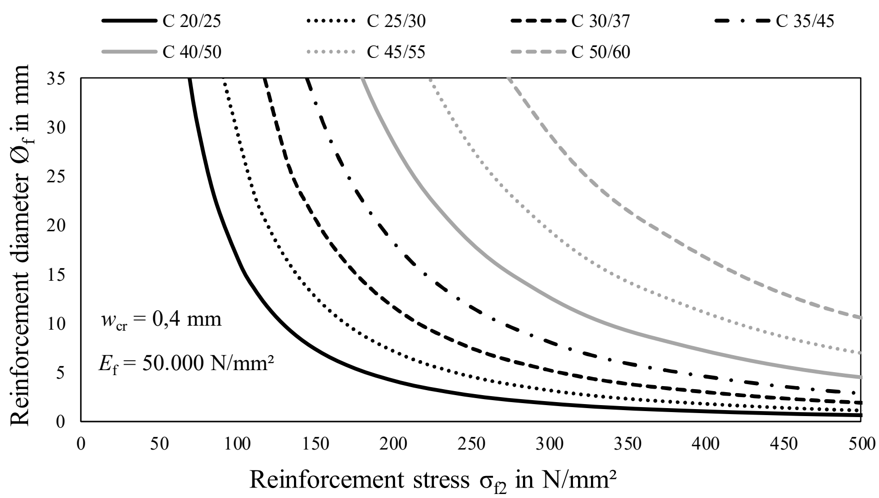

Figure 2-8: Indirect dimensioning diagram to limit crack widths from [2]

[1] Hofmann, S.; Tran, N.; Proske, T.; Graubner, C.-A. (2020): Cracking behaviour of BFRP reinforced concrete. An approach for the determination of crack spacing and crack width, In: Structural Concrete 2020. S. 2178–2190. Wiley

[2] Hofmann, Sebastian (2021): Rissentwicklung in Betonbauteilen mit Basaltfaserkunststoffbewehrung. Ein Modell zur Berechnung der Rissbreite bei wirklichkeitsnaher Betrachtung des Verbundverhaltens. Dissertation. Technische Universität Darmstadt, 2021

LOAD-BEARING BEHAVIOR OF STATICALLY INDETERMINATE TWO-SPAN BEAMS WITH GFRP REINFORCEMENT

Jonas Klein

The load-bearing behavior of concrete components with fiber-reinforced polymers (FRP) as reinforcement materials has been the subject of many experimental investigations in recent years. While the vast majority of these investigations have been carried out on statically determinate single-span systems, only a few results are available on statically indeterminate systems. For this reason, experimental studies were carried out at the Institute of Concrete and Masonry Structures on two-span beams. The components were reinforced with glass fiber reinforced polymer (GFRP) reinforcement bars by Schöck Com-BAR [1]. In addition to the slenderness of the beams (span 2.25 m and 3.00 m), the degree of reinforcement and the relation between reinforcement in support and span region were also varied. Beams were each loaded to failure by a concentrated load at midspan. Figure 2-8 shows an example of the test specimen *2.25m_02*.

For reasons of practical relevance and the limited availability of GFRP stirrups, no shear reinforcement was used in the form of reinforcing steel or GFRP. As expected, most of the components failed due to bending shear or shear failure in the center support area, as the shear slenderness was lowest with a/d = 6.2 (span 3.00 m) and a/d = 4.7 (span 2.25 m). It was noticeable that the calculated shear capacity - determined according to Muttoni [2] - was far exceeded in every test. Depending on the degree of reinforcement, a crack pattern typical for GFRP components developed until the failure of the components.

Figure 2-9: Specimen 2.25m_02

By measuring the support force under the middle support, it was possible to determine the internal forces in the specimen, assuming the same load application in both fields. It could be seen that, after reaching the crack moment, the internal forces shifted to the cross-sectional areas with a higher degree of reinforcement.

Finally, Figure 2-10 and Figure 2-11 show exemplary load-deflection curves of two test specimens. The deformations were also calculated using two analytic approaches. For this purpose, the approach proposed in [1] according to DAfStb Heft 533 and the calculation method according to ACI 440.1R-15 [3] were used. For the most part, there is a good correlation with the test results. However, the approach according to [1] slightly overestimates the deformations in some cases, while the approach according to [3] underestimates them in others. Nevertheless, it can be said that the deflections of GVFK-reinforced two-span systems can be reasonably predicted with both calculation methods.

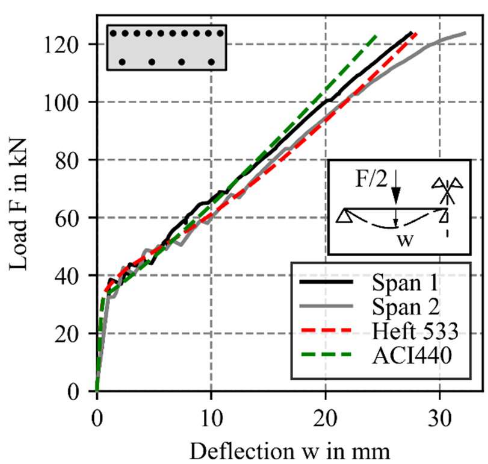

Figure 2-10: Load-deflection-diagramm Beam 2.25m_01

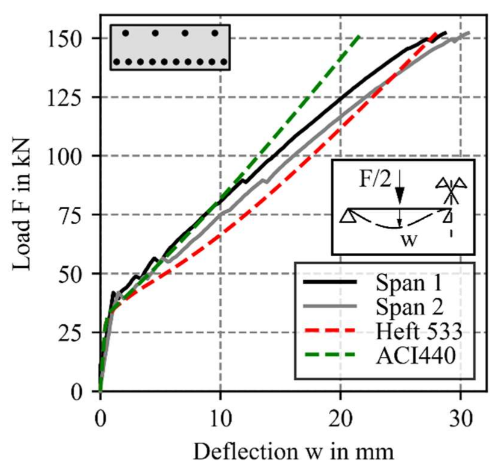

Figure 2-11: Load-deflection-diagramm Beam 2.25m_03

[1] Z-1.6-238 (2019): Allgemeine bauaufsichtliche Zulassung - Bewehrungsstab Schöck ComBAR aus glasfaserverstärktem Kunststoff. Berlin: Deutsches Institut für Bautechnik (DIBt).

[2] Muttoni, A.; Ruiz, M. F.; Cavagnis, F. (2018): Shear in members without transverse reinforcement: from detailed test observations to a mechanical model and simple expressions for codes of practice. In: fib Bulletin 85: Towards a rational understanding of shear in beams and slabs, S. 17–32. Fédération Internationale du Béton.

[3] ACI 440.1R-15 (2015): Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars. Farmington Hills, Michigan, USA. American Concrete Institute.

MODIFIED PARTIAL FACTORS FOR EXISTING SOLID CLAY BRICK MASONRY

Dominik Müller

For the structural assessment of masonry in the course of the extension or conversion of existing buildings, suitable partial factors are required that consider the particularities of existing masonry. These particularities include the material variability of older existing masonry that is usually much higher than for contemporary masonry, limited knowledge of the actual in-situ strengths due to small sample sizes in material testing, and a target reliability index that, where applicable, might be reduced compared to the design of new masonry structures.

Therefore, as part of a research project [1], carried out at the Institute for Concrete and Masonry Structures and funded by the program "*Zukunft Bau*", and a related dissertation [2], a method for determining modified partial factors γ_M for the compressive strength of existing masonry was developed. The basic approach of this method is that there is no single suitable partial factor γ_M for existing masonry structures. Due to the great variety of existing masonry and different corresponding boundary conditions, structure-specific partial factors γ_M must be determined. These partial factors depend on the number of compressive strength tests on unit and mortar specimens (or composite specimens), the material variability observed in these tests, and the specified target reliability index for the considered structural member. In [1] and [2], the method is described in detail, including its development and preparation for the application in engineering practice.

The developed method was applied to actual test data of existing masonry structures to investigate which partial factors γ_M usually result from the method. Only solid clay brick masonry was considered. The majority of investigated buildings was constructed between 1850 and 1950. A total of 78 existing masonry populations from 67 buildings were examined, for each of which at least three brick and three mortar specimens from at least two sampling locations were tested. A population included all masonry walls of a building that belong to the same masonry type (i.e. the same unit-mortar combination).

The evaluation was first carried out for a target reliability index of $\beta_{t,50a}$ = 3.8 (reference period 50 years), which corresponds to the reliability level defined in EN 1990:2002 for new structures of medium consequence class. In addition, partial factors were determined for a target reliability index of $\beta_{t,1a}$ = 3.3 (reference period one year). This reliability level is recommended in

ISO 2394:2015 for medium failure consequences and high relative costs for achieving a certain reliability level. The latter assumption is usually applicable to existing structures due to the high costs of retrofitting measures. The relative frequencies of the resulting partial factors γ_M are displayed in Figure 2-12.

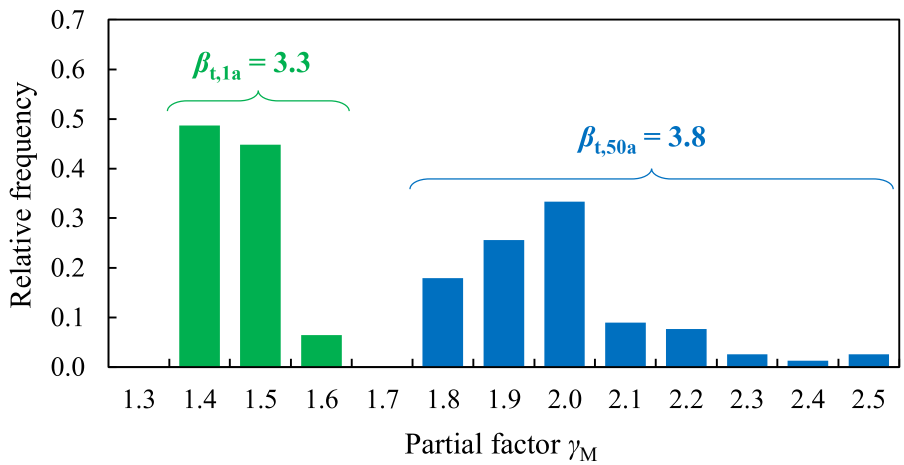

Figure 2-12: Partial factors resulting from the application of the developed method to 78 populations of existing solid clay brick masonry

It is evident that the resulting partial factor γ_M strongly depends on the selected target reliability index. For the considered buildings, applying the common reliability level for new structures results in an average partial factor of about $\gamma_M = 2.0$. Compared to the partial factor of $\gamma_M = 1.5$, which is specified for new masonry structures in DIN EN 1996-1-1/NA:2019, the significant increase results from the material variability that is usually much higher for existing solid clay brick masonry and the statistical uncertainty caused by small sample sizes. If $\beta_{t,1a} = 3.3$ is applied, the average partial factor is $\gamma_M = 1.45$. Hence, the higher uncertainties are more than compensated by the reduced target reliability index. Finally, it is noted that the reduced target reliability level additionally justifies a reduction of the partial factors γ_G and γ_Q for load effects; see also [2].

[1] Müller, Dominik; Proske, Tilo; Graubner, Carl-Alexander (2021): Modifizierte Teilsicherheitsbeiwerte für Mauerwerkswände im Bestand. Bonn: BBSR-Online-Publikation 24/2021.

[2] Müller, Dominik (submitted): Probabilistic Assessment of Existing Masonry Structures – The Influence of Spatially Variable Material Properties and a Bayesian Method for Structure-Specific Partial Factors. Dissertation. Technische Universität Darmstadt.

2.2 RESEARCH FIELD: BUILDING MATERIALS

The research area "*Mineral and ecological building materials*" focuses on ecologically optimised structural concretes, ecologically optimised cements, self-compacting concretes and fresh concrete pressure on formwork.

The aim of the research area "*Ecologically optimised structural concretes*" is the development of so-called "*Green Concretes*" or "*Eco-Concretes*". These concretes are composed in such a way that the environmental impact resulting from the production of the raw materials and the concrete production is as low as possible. In several research projects, Eco-Concretes are currently being developed with the participation of the precast concrete industry and ready-mix concrete producers, with which load-bearing concrete members can be produced in the near future.

By reducing the water content, switching to a high-performance superplasticizer and significantly increasing the limestone powder content, a significant reduction in the clinker content was achieved while maintaining the concrete compressive strength. All in all, the cement-reduced Eco-Concretes have a global warming potential that is reduced by approx. 30 % to 60 % compared to conventionally used concretes.

LIMESTONE POWDER AND GROUND GRANULATED BLAST FURNACE SLAG AS SUPPLEMENTARY CEMENTITIOUS MATERIALS

Christian Herget

In order to reduce global emissions of greenhouse gases, the concrete industry must also make a major contribution with new processes and concrete compositions. To reduce the damaging CO_2 emissions of the Portland cement clinker production with 0.82 t CO2/t clinker, the Portland cement clinker can be replaced or supplemented by other clinker substitutes or concrete admixtures. These include reactive materials, such as ground granulated blast furnace slag, fly ash or calcined clays, as well as inert fillers made from ground rock. Suitable mineral powders, such as limestone powder, which is already permitted in the standard as a main cement constituent, are available worldwide in very large quantities. Due to the easy grindability of limestone and the comparatively high compressive strength of the rock, it is very well suited to replace Portland cement clinker. It should be noted that, due to its inert properties, limestone powder only has a physical effect on strength and durability. As a result, the water content must be lowered. However, due to the physical, packing density improving properties of limestone powder, it has been shown that they achieve a small contributory effect on compressive strength and thus can theoretically be credited to the w/c ratio as a concrete admixture to achieve an equivalent w/c ratio [1].

With such creditability factors for limestone powder and ground granulated blast furnace slag, also called k value, it is possible to significantly reduce the contents of Portland cement clinker in more environmentally friendly eco-concretes. It is shown that at a constant equivalent w/c-ratio, crediting limestone powder with $k_{KSM} = 0.15$ achieves compressive strength and durability of concrete made with the reference cement. However, by adding blast furnace slag ($k_{HÜS} = 0.6$, EN 206-1), higher strengths and also carbonation depths, within the normative limits, are obtained, as shown in Figure 2-13. Here, CEM I a and b are respectively the two reference cements of the investigations. This means that, if up to 50 wt.% limestone powder is added, about 30 % of the cement-based emissions in the concrete can be saved. In this case, limestone powder and ground granulated blast furnace slag are added at 100 % to the cement content, thus keeping the paste content constant, which is essential for the durability and workability of the concrete.

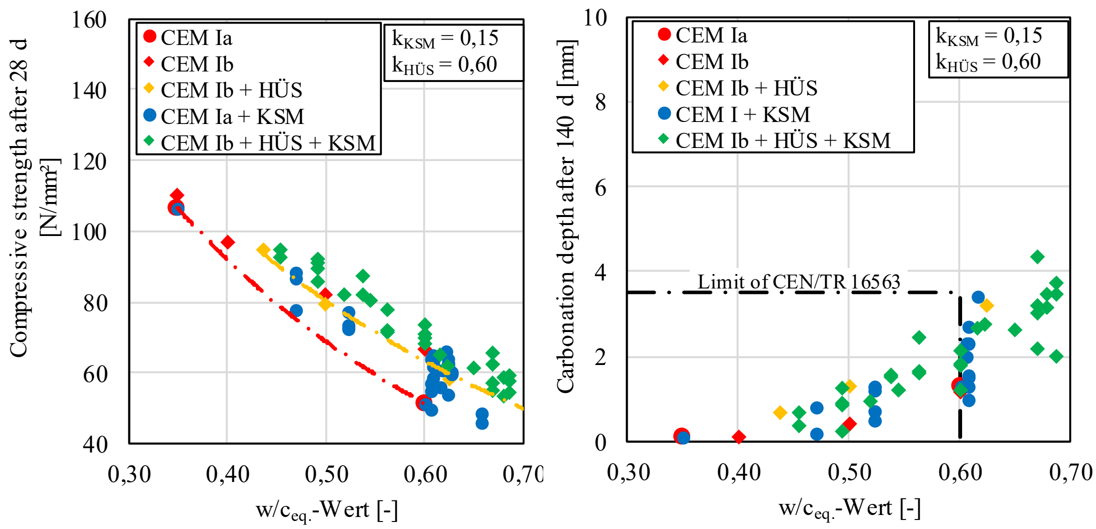

Figure 2-13: Comparison between equivalent w/c ratio and concrete compressive strength (left) and carbonation depth (right) for combinations of CEM I, ground granulates blast furnace slag (HÜS) and limestone powder (KSM) [1]

By using granulated ground granulated blast furnace slag and limestone powder as concrete admixtures, the composition of the concretes can be finely graded so that desired strengths and durability are precisely achieved. Thus, it is theoretically logistically possible to produce 11 cements according to DIN EN 197-1/-5 internally with only 3 silos within a concrete plant, depending on the required composition. This allows an efficient use of Portland cement clinker and concrete admixtures.

[1] *Herget, C., Müller, A., Proske, T., Rezvani, M., Graubner, C.-A.:* Kalksteinmehl als Betonzusatzstoff – Vorschlag für die Anrechenbarkeit auf den Zementgehalt und Potenzial zur CO 2 -Reduktion im Betonbau. Beton- und Stahlbetonbau 109 (2021), S. 202.

REDUCTION OF THE MINIMUM CEMENT CONTENT FOR THE DESIGN OF ECO-FRIENDLY CONCRETES

Anna Louisa Müller

With an annual production volume of approx. 4 billion tonnes of cement, the cement and concrete industry is responsible for 8% of global CO2 emissions. Besides substituting Portland cement clinker in the cement, one possible approach for improving the ecological impact of concrete, is to reduce the cement content in the concrete to the necessary minimum. In order to ensure sufficient durability of concrete, DIN 1045-2:2008 contains limit values for the minimum cement content and the maximum water-cement ratio (w/c ratio) depending on the exposure class. In Germany, the minimum cement content has been standardised for over 100 years and has only changed slightly since then. However, since cements and concrete admixtures have developed considerably, especially in the area of high-performance superplasticisers, these values must be critically questioned.

Studies, such as [1; 2], have already shown that the compressive strength in concrete depends not only on the existing w/c ratio, but also on the paste content in the concrete. The smaller the mortar paste thickness between the aggregates or the smaller the distance between the cement particles, the higher the compressive strengths achieved. In order to further investigate the suitability of ecological concretes with cement contents below the limits of the standard, concrete mixtures with cement contents between 320 and 200 kg/m³ concrete were produced. The w/c ratio for all mixtures was 0.6. This results in a significant decrease in the paste volume at reduced cement contents. In order to ensure the workability and compactability of the concrete, the grading curve of the aggregate was approximated to a U8 or U16 grading curve, as these have a very low water demand. In addition to sand and gravel, 7 wt.% fine quartz sand with a fines content of 68 % was added to the concrete mixes. As a result, with a moderate addition of superplasticiser, a soft consistency (spreading dimensions of approx. 43 cm) and good compactability could be achieved in all mixtures.

Figure 2-14 shows the compressive strengths of concretes with different cement and paste contents after 2 and 28 days. The concretes were produced with a maximum grain size of 8 and 16 mm. The figure shows that the compressive strengths do not deteriorate with decreasing cement content. Overall, the compressive strengths are slightly higher with smaller maximum grain size. On the other hand, the mixtures with a larger maximum grain size were easier to process, so that the cement content could be reduced to 200 kg/m³. First results of the tests of the carbonation depth, the chloride penetration resistance and the freeze-thaw resistance also show that the durability properties remain constant or improve with reduced cement contents and a constant w/c ratio.

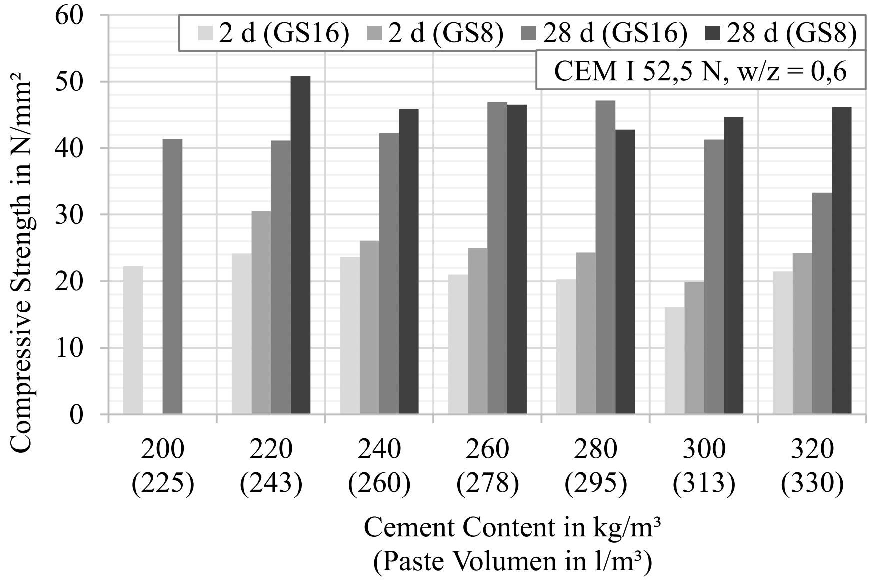

Figure 2-14: Concrete compressive strength after 2 and 28 days depending on cement content

[1] *Haist, M., Moffatt, J. S., Breiner, R., Müller, H. S.*: Entwicklungsprinzipien und technische Grenzen der Herstellung zementarmer Betone. Beton- und Stahlbetonbau 109 (2014), S. 202–215.

[2] *Chu, S. H.:* Effect of paste volume on fresh and hardened properties of concrete. Construction and Building Materials 218 (2019), S. 284–294.

2.3 RESEARCH FIELD: ENERGY AND SUSTAINABILITY

Research Field: Energy Research

The German federal government has set ambitious climate protection targets until 2050: At least 80 % of the gross electricity consumption and 60 % of the gross final energy consumption shall be covered by renewable energies. Buildings play a key role in this project as the building stock not only accounts for a quarter of annual final energy consumption, but also forms a central interface between the electricity, heating and mobility sector. Innovative energy technologies can be used efficiently, ecologically and economically, especially on the urban scale, and can lead to a stronger coupling of these sectors.

The Institute of Concrete and Masonry Structures makes an essential contribution to the energy system of tomorrow mapping energy requirements in high temporal resolution, conducting dynamic simulations of energy concepts or developing concepts for the utilisation of excess energy.

Research Field: Sustainable Design

In the context of the progressive destruction of our environment, aspects of sustainable development are becoming increasingly important. In regard to this, the field of civil engineering offers great potential for development. Factors such as a high commitment of resources, complex emissions and the still often limited application of integral planning are only some of the elements of a wide field of action, which is equally of economic, ecological and social importance.

Research in the field of sustainable development has been one of the central fields of work of the Institute of Concrete and Masonry Structures since 1997. A number of software tools have been developed in recent years to carry out a holistic analysis and assessment of buildings over their entire life cycle. From the planning phase to the construction, operation and disposal phases, all relevant economic and ecological features of a building can be recorded and evaluated over its entire life cycle.

ESTIMATION OF THE SELF-CONSUMPTION OF ELECTRICAL POWER FROM BUILDING RELATED PHOTOVOLTAIC SYSTEMS

André Müller

When it comes to the optimal sizing of building mounted or building integrated photovoltaic (PV) systems, building owners, architects and energy consultants often face the problem of estimating a reliable value for a household's self-consumption, which is needed as an input for the calculation of the profitability of a specific PV system. The balancing methods which form part of the energy performance certificates calculation lead to an overestimation of PV self-consumption, but only consider electricity consumption for heating, cooling and ventilation appliances. More sophisticated simulation tools come with a higher effort for planners. [1] Against this background a formula for an estimation of PV self-consumption for households was derived from a parametric study, which allowed the calculation of PV self-consumption values depending on the ratio of annual PV generation and the total energy consumption of the household.

The stochastic occupant behavior model PeakTime by Wörner [2] forms the basis of the study conducted. Occupant behavior profiles for 400 households were simulated and the occupancy, electricity and domestic hot water demand were used as an input for a parametric study with the building simulation software IDA ICE. The subject of investigation was a building model for a single-family home with an air-to-water heat pump as heat source with the parameters varied as shown in table 1 and an annual electricity generation of the PV system ranging from 2 MWh/a to 20 MWh/a with increments of 2 MWh/a. (cf. [1], see Figure 2-15). In total, a dataset of 56.000 calculations resulted from the parametric study.

Table 2-1: Varied parameters and their values

Parameter	Description	Values
Energy performance level of building	Performance of the thermal envelop of the building model (cf. table 2 in [1])	Refurbished; GEG; $KfW40_{2020}$
Room temperature set point	Schedule of constant room temperature with a nightly setback between 11 pm and 6 am	20 °C - 3 K; 21 °C - 3 K; 22 °C - 3 K
Location and climate file	Test reference year (TRY) 2015 data for locations as defined in VDI 4655 (2019)	Potsdam; Mannheim; Garmisch-Partenkirchen
Orientation of the roof ridge	0° is a roof ridge in north-to-south direction; counting direction is counter-clockwise	0°; 45°; 90°; 135°

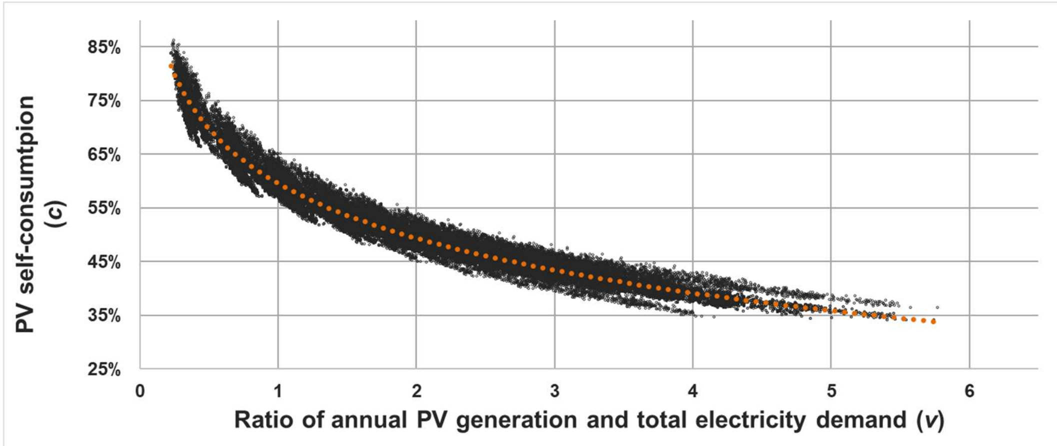

Figure 2-15: PV self-consumption for 56.000 data point of the parametric study with annual electricity generation from PV from 2 MWh to 20 MWh

The temporal resolution of the calculation of PV self-consumption is 5 minutes. A visual inspection and comparison of regression models with MS Excel led to the conclusion, that a logarithmic estimation function fits well the shape of the point cloud from the parametric study (R^2 = 0,9712). The resulting formula is given in equation (1). A further, statistical profound analysis of the dataset was not yet conducted and has to substantiate the estimation formula presented here.

$$c_{self-consumptio} = -0{,}147 \ln(v) + 0{,}5958 \quad (1)$$

Acknowledgement

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[1] Müller, André; Koert, Johannes; Wörner, Patrick (2021): Household specific self-consumption of photovoltaic-based power generation – a comprehensive parametric study to increase the reliability of energy consulting. In: Proceedings of the 17th IBPSA International Conference and Exhibition, Building Simulation 2021, 1.-3. September 2021, Bruges, Belgium.

[2] Wörner, Patrick (2020): Einfluss des Nutzerverhaltens auf den Stromverbrauch in Wohngebäuden – Entwicklung eines komplexen Simulationsmodells für energetische Analysen. Dissertation. Darmstadt: Institut für Massivbau, Technische Universität Darmstadt.

ASSESSMENT TOOL FOR ENERGETIC REFURBISHMENT OF TYPICAL NEIGHBORHOODS

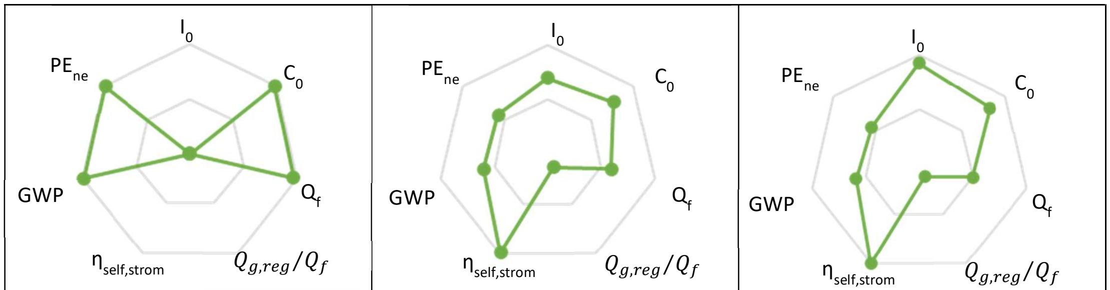
Johannes Koert

Within the framework of the research project "*Integration of renewable energy sources in the energy supply of networked city neighborhoods (E4Q)*", funded by the German Federal Ministry of Economics, a tool was developed at the Institute of Concrete and Masonry Structures, which can be used for the comparison of variants of refurbishment and energy supply concepts of typical city neighborhoods.

The tool is based on the results of extensive simulations of the energy demand profiles of the typical neighborhoods in various designs with regard to the building component qualities, climatic and usage conditions as well as the system technology for heat generation, storage and transfer at the building and neighborhood level. In addition, the tool contains data sets on the costs and environmental impacts of building components and system technology components. Users of the tool have the possibility to define the status quo of the considered neighborhood as well as the renovation variants to be examined by means of an implemented graphical user interface. The LCA and life cycle costs of the variants can then be calculated automatically. The calculation methods used represent a further development of the procedure of Weißmann [1].

The indicators greenhouse gas potential (GWP), non-renewable primary energy demand (PE_{ne}), net present value (C_0), investment costs (I_0), final energy demand (Q_f) as well as the share of renewable energy ($Q_{g,reg}/Q_f$) and the degree of self-sufficiency of the renewable generated electricity (η_{self}) are used to formulate the evaluation results. Thus, the economic, ecological and energetic dimensions of the decision problem can be described.

As an example, the results of an evaluation are shown in Figure 2-16. A block edge neighborhood from the 1960s is assumed in its unrefurbished initial state with decentralized natural gas-fired heat supply. As two renovation variants, a networked heat supply using a central gas-fueled combined heat and power unit (CHP) with two different insulation levels of the building shells is considered. The second (more highly insulated) variant is rated better in the energy and ecological indicators. However, both the investment costs and the net present value of the life cycle costs are higher for this variant, since the higher investment of the insulation cannot be amortized by the energy savings. Which variant the users choose depends on the individual preference of the weighting of the evaluation indicators.



GWP	1489	kg $CO_{2,eq}$/m²
PE_{ne}	5933	kWh/m²
I_0	91	€/m²
C_0	684	€/m²
Q_f	92	kWh/(m²*a)
$Q_{g,reg}/Q_f$	0	%
η_{self}	0	%

GWP	901	kg $CO_{2,eq}$/m²
PE_{ne}	3484	kWh/m²
I_0	91	€/m²
C_0	529	€/m²
Q_f	57	kWh/(m²*a)
$Q_{g,reg}/Q_f$	13	%
η_{self}	99	%

GWP	879	kg $CO_{2,eq}$/m²
PE_{ne}	3294	kWh/m²
I_0	120	€/m²
C_0	571	€/m²
Q_f	48	kWh/(m²*a)
$Q_{g,reg}/Q_f$	12	%
η_{self}	100	%

Figure 2-16: Evaluation indicators of an exemplary study of a block-edge neighborhood a) unrefurbished status quo with decentralized gas boilers (left), b) central CHP with H_T' 85% to GEG level (middle) and c) central CHP with H_T' 55 % to GEG level (right).

[1] Weißmann, Claudia (2017): Integration of renewable energy sources in networked residential neighbourhoods: Development of a simulation-based method for energetic, ecological and economic evaluation. phd-thesis. Technical University Darmstadt.