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EDITORIAL AND REVIEW OF THE YEAR

Dear Friends and Partners of the Institute of Concrete and Masonry Structures,

with the 32nd edition of "Darmstadt Concrete" we would like to inform you in good tradition about the activities of the institute in research, teaching and committee work in the past year 2017 and at the same time inform you about current personnel changes. What has already become apparent in the past few years has now also been formally completed: The divisions "Construction and Building Materials" and "Constructive Design and Building Construction" have been established as independent institutes by the Department of Civil Engineering and Geodesy at the Technical University of Darmstadt and are therefore no longer part of the Institute of Concrete and Masonry Structures. Thus, in future, this report will only contain information on the research and teaching of the former Division of Concrete and Masonry Structures, which is now solely known as the Institute of Concrete and Masonry Structures (Institut für Massivbau). We hope that this overview of our activities will be of interest to you and we hope you enjoy reading it.

Two special events were organised in 2017 in cooperation with the Friends of the Institute of Concrete and Masonry Structures. On the occasion of the 60th birthday of Prof. Graubner at the beginning of September 2017, current and former research assistants decided to organise an internal festival colloquium on 23rd September 2017, at which about 50 former and current research assistants could meet once again, get to know each other and exchange information professionally and privately. A very personal lecture by Prof. Dr.-Ing. Shelley Lissel and five other presentations of former assistants on their professional career after graduation made the afternoon a special event, as not only technical, but above all, very individual experiences were presented. An evening event in the old railway station in Mühltal topped off the very successful event.

On 9th November 2017 the 39th Darmstädter Massivbauseminar took place, which was organised under the qualified supervision of Prof. Dr.-Ing Katharina Klemt-Albert with the title "Digitalisation in Construction - Challenges for Structural Engnineering", dealing with the

latest developments on the topic of "Building Information Modeling (BIM)" and the consequences for structural engineers in terms of technical, personnel and legal aspects. Ten speakers discussed these aspects from different angles and the participants had the opportunity to exchange their experiences in this field.

In 2017, a total of 12 lecture modules, 28 bachelor's theses and over 42 master's theses were supervised. Currently, about 6 major research projects are in progress. In this context, we are very proud of the acquisition of two DFG projects. The first one, which was won in cooperation with the Institute of Concrete Structures at the Technical University of Dresden, was acquired as part of the SPP 2020 priority programme "Cyclical Damage Processes in High-Performance Concrete in the Experimental Virtual Lab". The project "Influence of load-induced temperature fields on the fatigue behaviour of UHPC under pressure swell loading" is scientifically investigated by Dr.-Ing Linh Tran, who has been working for us as a post-doc for many years. We are also involved in the currently largest German construction research project "C^3 - Carbon Concrete Composite" with 2 projects. Furthermore, in cooperation with the Institut Wohnen und Umwelt (Institute for Housing and Environment), Darmstadt, a major project for the energetic interconnection of urban districts is currently in the hopefully successful application phase at the Federal Ministry of Economics and Technology. We have further intensified our cooperation with the Swiss Federal Laboratories for Materials Testing (EMPA). Our research assistant Sarah Steiner, who works for us as a scholarship holder of the Graduate School of Excellence Energy Science and Engineering, was scientifically active in Dübendorf during the summer. In this context, we would like to thank the Darmstadt Graduate School for the fact that three of its scholarship holders are currently able to do research at our institute.

Employees and students of the Institute were also able to win a number of prizes in 2017. Dr.-Ing Ulf Grziwa was awarded the prize for his excellent dissertation at the annual meeting of the Friends of the Institute of Concrete and Masonry Structures. Johann Kraft received the prize of the Friends of the Institute for the best master thesis in the field of concrete construction. Melanie Stöcker received the first prize of the Fachvereinigung Deutscher Betonfertig-

teilbau e. V. for outstanding academic achievements in the field of prefabricated constructions. Maximilian Bienhaus took first place in the category of civil engineering of the Hessian Construction Industry Association for his master thesis. Finally, this year's Dreßler Prize - donated by our member company Dreßler Bau GmbH - went to Dominik Hiesch, who dealt with the design of textile concrete members under bending moments in his bachelor thesis.

In addition to presenting the achievements made, this year's review should also serve to thank our employees for their work and commitment. Without the high quality and tireless dedication with which our scientists, as well as our staff in the secretariat, the technical service and the laboratories approach their tasks and projects, the achievements and successes of our Institute in 2017 would not have been possible.

In 2017, a number of assistants at our Institute were able to complete their dissertation. We would like to congratulate:

Dr.-Ing **Ulf Grziwa**:	Zuverlässigkeit schlanker UHPC-Druckglieder mit räumlich streuenden Materialeigenschaften
Dr.-Ing. **Björn Freund**:	Frischbetondruck lotrechter, geneigter und gekrümmter Betonbauteile bei Verwendung von Betonen mit hoher Fließfähigkeit
Dr.-Ing. **Gökhan Uysal**:	Kostenrisiken von Industriebauten mit flexiblen Nutzungsszenarien
Dr.-Ing. **Moien Rezvani**:	Shrinkage model for concrete made of limestone-rich cements
Dr.-Ing. **Claudia Weißmann**:	Effizienter Einsatz erneuerbarer Energieträger in vernetzten Wohnquartieren
Dr.-Ing. **Michael Schmitt**:	Tragfähigkeit ausfachender Mauerwerkswände unter Berücksichtigung der verformungsbasierten Membranwirkung

In addition, an external research assistant finished his dissertation at the Institute of Concrete and Masonry Structures:

Dr.-Ing. **Markus Blatt**: Beitrag zum Trag- und Verformungsverhalten von Stahlbeton-deckenknoten

Dr.-Ing. Ulf Grziwa, Dr.-Ing. Björn Freund and Dr.-Ing. Michael Schmitt have already taken responsible positions in the engineering industry. Dr.-Ing Gökhan Uysal continues to work for an automotive company in Munich. Dr.-Ing. Moien Rezvani will accompany an already approved research project of the German Research Association (DFG) on the topic of "*Shrinkage of clinker-reduced concrete from cements with high limestone content*" holding a postdoctoral position at the institute. Valentin Förster, who has already submitted his dissertation on the topic " *Tragfähigkeit unbewehrter Beton- und Mauerwerksdruckglieder bei zweiachsig exzentrischer Beanspruchung*", will leave the institute at the end of the year and join an engineering consultancy.

We welcome as new employees:

André Müller, M.Sc. - January 1st, 2017

Sebastian Hofmann, M.Sc. - March 1st, 2017

Jonas Klein, M.Sc. - January 1st, 2018

Marleen Fischer, M.Sc. - January 1st, 2018

Last year, Tarek Alzab, a civil engineer who fled from Syria, was a member of the support programme of the Federal Environment Foundation (Deutsche Bundesstiftung Umwelt). After Tarek Alzab had been able to greatly improve his German language skills and developed his professional skills, he succeeded in getting a job at a medium-sized construction company. Congratulations and good luck.

Last but not least, we would also like to thank the Friends of the Institute of Concrete and Masonry Structures of the TU Darmstadt e. V.. Without their support, many small and also larger activities at and for the institute and the students would not have been possible. We

would like to take this opportunity to thank the Chairman of the Board of Directors, Dr.-Ing. M. Six, the treasurer Dipl.-Ing. D. Hanek, as well as the members of the Board of Directors, Prof. Dr.-Ing. K. Klemt-Albert, Dr. -Ing. G. Riegel and Dr.-Ing. G. Simsch, who provide us with ongoing advice, support and benevolent support in a variety of ways.

The following short reports in both German and English give you a brief insight into the scientific activities of our employees. If you are interested, please contact us. A compilation of the scientific publications of the institute in 2017 and further information can be found on the homepage of the institute:

www.massivbau.tu-darmstadt.de

On behalf of the entire Institute of Concrete and Masonry Structures, we wish you and your family a peaceful holiday season and a good start into the new year.

Prof. Dr.-Ing. Carl-Alexander Graubner

Dr.-Ing. Tilo Proske

COLLABORATION IN STANDARDISATION COMMITTEES

In 2017, Prof. Graubner will continue his occupation as the chairman of the standardisation committee NA 005-06-01 AA “Masonry Structures”, the leading national standards committee dealing with issues of standardisation in the field of masonry structures. In this context, it should be mentioned that Prof. Graubner was elected as Vice Chairman of the Steering Board NABau Fachbereich 06 “Masonry Structures” in 2016. This board is the top level DIN standardisation committee in the field of masonry structures and coordinates all national and international standardisation activities. Prof. Graubner also acts as the German delegate on the European level and is member of the European standardisation committees Scientific Committee 6 and Working Group 1 as well as of Project Team 2. Furthermore, Prof. Graubner is Chairman of Project Group 5 of the initiative “Praxisgerechte Regelwerke im Bauwesen e.V.” Apart from that, he is elected member of the standardisation committee NA 005-07-01 AA “Design and Construction of Reinforced Concrete”. As a member of different expert groups, Prof. Graubner supports the German Centre of Competence for Construction (DIBt) in Berlin.

Following the aforementioned activities in the field of masonry structures, Prof. Graubner is editorial advisor for the journal “Mauerwerk” since 2012. Moreover, since 2016 he is author of the chapter “Masonry” in the well-known “Schneider Bautabellen” and he is editor and co-author of the book “Mauerwerksbau – Praxishandbuch für Tragwerksplaner”, which presents the newest developments in research and practice in the field of masonry structures.

Further on, Prof. Graubner is a representative expert of the “Graduate School of Energy Science and Engineering”.

SEMINARS AND EVENTS

Training seminar for structural engineers

The Institute of Concrete and Masonry construction cordially invited engineering experts to the 2017 seminar series. Speakers with practical expert knowledge give presentations on newest developments in civil engineering. Throughout the year we were able to attract more than 750 structural engineers. The seminar series was almost fully booked and followed the established event concept. The seminar series in 2017 gave an overview of the latest technical developments in the field of civil engineering. In spring of 2017 the issues of calculation examples of steel composite constructions, construction errors and structural damage and the dimensioning of fastening elements in concrete structures were treated. In autumn the lectures treated tools for the design of concrete structures, calculation examples for prestressing in structural engineering and contained a new format "You ask, we answer". Below you find all six individual seminars:

- Steel Composite Constructions – Calculation Examples | 15.02.2017
- Construction Errors and Structural Damages | 01.03.2017
- Dimensioning of Fastening Elements in Concrete Structures | 15.03.2017
- Tools for the Design of Concrete Structures | 13.09.2017
- Prestressing in Structural Engineering – Calculation Examples | 27.09.2017
- New: "You ask, we answer" | 11.10.2017

Due to the positive feedback from the past years, we will organise the seminar again in 2018. We are confident that the combination of interesting topics and renowned speakers will again attract many structural engineers.

- Energy efficient buildings according to EnEV 2016 and GEG | 28.02.2018
- Innovative reinforcement for concrete elements | 07.03.2018
- Indirect action in concrete structures | 21.03.2018
- Fire protection | 12.09.2018
- Building Information Modelling (BIM) | 26.09.2018
- Design of formwork | 10.10.2018

Updates on the seminars as well as the registration can be found on the homepage of the Institute of Concrete and Masonry Structures (www.massivbau.tu-darmstadt.de) under the section „Veranstaltungen". In case of questions, please do not hesitate to contact Mr. René Mazur, M.Sc.

Darmstadt Days of Prefabricated Concrete Elements

Due to our cooperation with the professional association “Deutscher Betonfertigteilbau e. V. (FDB)” and the “InformationsZentrum Beton”, we were able to host the renowned seminar series “Darmstadt Days for Prefabricated Concrete Elements” in 2017 for the 10th time. The presented topics varied from the characteristics of prefabricated constructions, which already begin with the initial sketch, to special construction elements and corresponding methods, such as on-site concrete additions or prestressed constructions. Further, stability considerations define a focal point with examples, such as lateral buckling and the design and construction of the connections. In this year, about 100 structural engineers and students participated in the event. The seminars were complemented by an exhibition of renowned manufactures of construction products related to the topic of precast construction.

Abbildung 1: Award oft the prefabricated construction price (from left to right: Professor Graubner (TU Darmstadt), Melanie Stöcker (Preisträgerin), Elisabeth Hierlein (FDB e.V.))

Generally speaking, the seminar content is tailored towards practical engineers. However, a separate “student day” takes place in which the design of precast concrete elements will be treated. Thus, the lecture “prefabricated constructions”, which takes place in the context of the Darmstadt Days of Prefabricated Concrete Elements, can be incorporated into the student’s

study design. The 10th anniversary was celebrated with a price for the best graduate of the lecture prefabricated constructions and will from now on be awarded every year. The price in 2017, which was awarded during the summer party of the “Verein der Freunde des Instituts für Massivbau”, went to Ms. Melanie Sabine Stöcker, who was able to stand out for her excellent results.

In the upcoming year, the seminar series with interesting lectures, practical examples and our well-attended exhibition is going to be celebrated for the 11th time. We are confident to attract a highly diversified audience with a combination of interesting topics and renowned speakers form science and practise. The following topics are expected to be discussed in the upcoming seminar series in spring 2018:

- 08.03.2018 | Basic Principles of Planning
- 09.03.2018 | Prefabricated Concrete Structures
- 15.03.2018 | Fire Protection Requirements und Connections
- 16.03.2018 | Concrete and Façade

Updates on the event can be found on the homepage of the Institute of Concrete and Masonry Structures (www.massivbau.tu-darmstadt.de). Enter the section named „Veranstaltungen“. In case of questions, please do not hesitate to contact Mr. Redouan El Ghadioui, M.Sc. or Mr. Jonas Klein M.Sc.

Celebration of the 60th birthday of Professor Graubner

On Saturday, 23rd September 2017, Professor Graubner invited all former and current scientific assistants and the board of the „Verein der Freunde des Instituts für Massivbau e.V.“ to celebrate his 60th birthday. In this context, the „Freunde-Verein“ organised a festive afternoon event at Lufthansa's conference hotel in Seeheim-Jugenheim. In addition to a review of the past 20 years of the Institute of Concrete and Masonry Structures, including the presentation of past and current research projects, the guests heard exciting lectures on this day and came together. So not only new acquaintances were made, but also old ones were strengthened again.

The evening ended in the restaurant "Vanille-Stadtkoch" in Mühltal-Traisa. In addition to delicious food and drinks, the former and current employees of the IfM reviewed the last 20 years at the institute in pictures and words.

Current and former doctoral students and employees of the Institute of Concrete and Masonry Structures celebrating the 60th birthday of Univ.-Prof. Dr.-Ing. Carl-Alexander Graubner

39th Darmstädter Massivbauseminar 2017: „Digitalization in Construction – Challenges for Structural Engineers“

The 39th edition of the Darmstädter Massivbauseminar took place on November 9 at the Campus Lichtwiese of the Technical University of Darmstadt. The aim of this year's Massivbauseminar was to give an insight into current developments in the field of digitalization in construction and to highlight the challenges structural engineers have to face because of this digitalization, which is growing quite fast. The seminar was once again organised by “Freunde des Instituts für Massivbau der TU Darmstadt e. V.” in cooperation with the Institute of Concrete and Masonry Structures.

View of the participants at the 39th Darmstädter Massivbauseminar

The speakers of the seminar were invited from various fields of the construction industry to examine the topic from very different perspectives. In this way, the guests of the seminar were able to find out what the progress of digitalisation means for planners and construction companies as well as for building owners and construction authorities, what the legal and the software-technical framework of digitalisation are and which effect the increasing digitalisa-

tion has on the job description of structural engineers. One focus of the seminar was the introduction of Building Information Modeling (BIM).

The programme of the 39th Darmstädter Massivbauseminar consisted of the following talks:

- Prof. Dr.-Ing. Katharina Klemt-Albert (ICoM, Universität Hannover):
  BIM – What is reality? What is still vision?

- Dr.-Ing. Horst Alexander Göllner (Deutsche Lufthansa AG):
  Application of the BIM method from the point of view of the client Lufthansa

- Hannes Schwarzwälder (Implenia Hochbau GmbH):
  BIM requirements from the point of view of a general contractor

- Momme Petersen (DB Netz AG):
  BIM pilot project Fehmarnsundquerung - BIM requirements of DB Netz AG

- Gabriele Hornung, Fernando Suarez Garcia (Bauaufsicht Oberursel):
  The digital building permit procedure in the cloud - practice report

- Markus Maier (Leonhardt, Andrä und Partner):
  Are you still drawing or are you already BIMing? Experiences with model-based planning in structural engineering

- Dr.-Ing. Matthias Bergmann (albert.ing GmbH), Robert Hartung (Uni Hannover):
  IT solutions for the BIM methodology in structural engineering - requirements and practical tests

- Dr. Nicolai Ritter (CMS Hasche Sigle):
  BIM - Legal framework and intellectual property rights

- Dirk Kahl (AS+P Albert Speer + Partner):
  BIM - More opportunities than risks from the architect's point of view

The chairmen of the “Freunde des Instituts für Massivbau der TU Darmstadt e. V.” would like to thank the speakers for their very exciting and interesting talks and all those involved for their effort, which has led to the success of the event.

EXCURSIONS

Whit Excursion to „Oberes Rheintal“

This year, the traditional whit excursion of the Institute of Concrete and Masonry Structures of the TU Darmstadt (Professor Graubner, represented by Dr.-Ing. Proske) and the Institutes of Steel Construction and Concrete and Masonry Structures of the University of Kaiserslautern (professors Kurz and Schnell (as well as future successor Mr. Dr.-Ing. Glock) took place again. In the week after whit, from 06th to 9th June 2017, this year's excursion to the upper Rhine valley (Oberes Rheintal) gave us numerous technical and cultural impressions.

The first day of the excursion led the group to the Main metropolis of Frankfurt, where the construction of the new exhibition hall No. 12 is being driven forward. In addition to that, the construction site of the Kornmarkt Arkaden was also visited, which represented a special challenge for those involved in the construction due to the historical facade. Before the participants of the excursion then traveled to the Kurhaus Trifels, the last stop led the excursion participants to the construction of the Schiersteiner Brücke, a new bridge in Mainz/Wiesbaden.

Day 2 began with a tour through the tunnel construction site on the new railway line Karlsruhe/Basel of the german railway company Deutsche Bahn. The excursion was continued at the factory of Badische Drahtwerke near the french border, where it was possible to take a look at how steel is made and finished. The evening ended with a dinner near Strasbourg, including original Alsatian Tarte Flambée and Pinot Noir.

On the third day of the excursion, the group visited the FEHR precast factory, the construction site of the new SAP headquarters building in Walldorf and BBV Systems, a company specialised in prestressing concrete structures. The group spent the last evening together in the Kurhaus Trifels with a delicious barbecue and bright weather.

The last day of the excursion began with a hike to Reichsburg Trifels and afterwards with an exciting lecture by Professor Dr.-Ing. em. Wieland Ramm on the Palatinate (Pfalz) as the cradle of reinforced concrete construction and on the life of Conrad Freytag. Fittingly, the company Wayss & Freytag led us through the construction site of the old IBAG halls afterwards, which were formerly used as production halls and are now converted into a prestigious resi-

dential building in loft style. The last programme of the excursion week was a visit to the mausoleum of the family of Freytag. Constructed in reinforced concrete, the mausoleum was built by Conrad Freytag, who deliberately chose this material and emphasised the esthetic potential of concrete through various surface finishing techniques. A relative of Mr. Conrad Freytag, who was in possession of the key to the mausoleum, opened the door to the group - an opportunity reserved only for a few visitors.

After a tightly scheduled and exciting excursion week, which was well organised by the TU Kaiserslautern, the participants were grateful for the new insights and impressions.

Figure 1: Participants of the whit excursion in the former IBAG-Halls

Excursion to the production facility of Viessmann at Allendorf/Eder

As part of the lectures Technische Gebäudeausrüstung I and Strategical Facility Management & Sustainable Design, an excursion to the production facility of Viessmann took place on Friday, 2nd December 2016. Twenty-seven students accompanied by three research assistants and Mr. Dipl.-Ing. Thomas Heß visited Viessmann, which is a leading manufacturer of heating systems and industrial energy systems in Allendorf/Eder.

The guided tour started with an overview on the company´s history and continued with a presentation of innovative renewable energy systems. Furthermore, the participants had the opportunity to visit the in-house production and the energy centre of Viessmann. After lunch, the participants went to the so-called Viessmann academy, where they were informed about combined heat and power systems, fuel-cell technologies and current developments in the field of digitalization and smart home solutions.

The participants of the excursion in the exhibition area of Viessmann at Allendorf/Eder

On behalf of all participants, the Institute of Concrete and Masonry Structures would like to thank Mr. Joschko and Mr. Daum (employees of Viessmann) for organising and carrying out the excursion and the interesting guided tour. This trip was only possible with the generous support of the Viessmann Company and the “Freunde des Instituts für Massivbau der TU Darmstadt e.V.”, to whom we express our sincere thanks.

PERSONAL MATTERS

Mr. André Müller, M.Sc. is a doctoral student at the Institute of Concrete and Masonry Structures since January 1st, 2017. He received his master's degree in "Energy Science and Engineering" in 2016 and is an associated member of the Darmstadt Graduate School of Excellence Energy Science and Engineering. His research activities at the Institute focus on the assessment of refurbishments in urban districts. More precisely, he will evaluate interconnected and non-interconnected as well as sector-integrated supply strategies for different types of urban districts regarding their potentials for the reduction of energy consumption and CO_2 emissions. Furthermore, Mr. Müller is responsible for the coordination of the lecture "Building Technology I". Aside from his work at the Institute of Concrete and Masonry Structures, Mr. Müller is employed at the Institute for Housing and Environment (Institut Wohnen und Umwelt GmbH) as a researcher in the fields of "strategic monitoring and development of the building stock" and "building assessment and optimization".

Since March 2017 Mr. Sebastian Hofmann, M.Sc. is employed at the Institute of Concrete and Masonry Structures. Mr. Hofmann studied civil engineering with the specialisation in concrete construction, steel construction and structural design at the TU Darmstadt. He wrote his master's thesis "The application of the principle of prestressing on steel I-profile beams and on composite beams" at the Universidad de Montevideo in Uruguay. After graduating, he initially worked at HOCHTIEF Engineering GmbH in Frankfurt am Main in the field of steel construction and engineering, before moving to Hilti Germany AG. There he worked as a consultant in special topics of fastening technology as well as in for component reinforcement when building up inventory. As part of his doctorate, Mr. Hofmann will initially be responsible for the projects of the Research and Testing Laboratory for Solid Construction.

AWARDS

Prizes of the „Verein der Freunde des Instituts für Massivbau der TU Darmstadt e.V.“ 2017

The annual prize of the „Verein der Freunde des Instituts für Massivbau der TU Darmstadt e.V.“ for the outstanding dissertation at the Institute in 2017 was awarded to **Dr.-Ing. Ulf Grziwa**. He wrote his doctoral thesis on "Reliability of slender UHPC compression members with spatially scattering material properties". We congratulate Dr.-Ing. Grziwa very much to this success!

In addition to the prize for the outstanding dissertation at the Institute of Concrete and Masonry Structures, the „Freunde-Verein“ also awards a prize to the student with the best master thesis at the Institute, which is donated by the GOLDBECK company. The prize was awarded this year to Mr. **Johann Kraft, M.Sc.** for his thesis titled "Calculations of prestressing losses for precast girders". We congratulate Mr. Kraft very much!

Awarding the prizes of the „Freunde-Verein“ on the annual summer party

Dreßler Bau Award 2017

The Dreßler Bau Prize has been awarded for the fifth time at the TU Darmstadt on 15th November 2017. The award is handed over for the outstanding bachelor thesis in the technical disciplines Concrete Structures and Construction Management. Mr. **Dominik Hiesch, B.Sc.** submitted his bachelor's thesis entitled "Development of a calculation-diagram for carbon-fibre reinforced concrete members under bending loads". We congratulate Mr. Hiesch on this success.

Prize of the Hessian building sector 2017

For the 34th time, the association of building contractors in Hessen (VbU) awarded the prize of the Hessian building sector. In the Civil Engineering category, **Mr. Maximilian Bienhaus, M.Sc.**, who has completed his master's thesis at the Institute of Concrete and Masonry Structures, succeeded. The master thesis was entitled "Development of concepts for prefabricated bridge caps". We congratulate Mr. Bienhaus on this achievement.

Awarding of the prize of the building industry in Hessen

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:

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Arbeitsgemeinschaft industrieller Forschungsvereinigungen „Otto von Guericke“ e.V.
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Beton Kemmler GmbH
Bundesanstalt für Straßenwesen
Bundesministerium für Bildung und Forschung
Bundesministerium für Verkehr und digitale Infrastruktur
Bundesministerium für Umwelt, Naturschutz, Bau- und Reaktorsicherheit
Bundesverband der Deutschen Ziegelindustrie
Bundesverband der Kalksandsteinindustrie e.V.
Bundesverband Porenbetonindustrie e.V.
Bundesverband Deutsche Beton- und Fertigteilindustrie e.V.
Bundesverband Leichtbetonzuschlagindustrie e.V.
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Deutsche Bundesstiftung Umwelt
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Deutsche Gesellschaft für Mauerwerks- und Wohnungsbau e.V. (DGfM)
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Deutsches Institut für Bautechnik
Dreßler Bau GmbH
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Empa Dübendorf
Fachvereinigung Deutscher Betonfertigteilbau e. V.
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Forschungsinstitut der Zementindustrie (FiZ)
Forschungsvereinigung Kalk-Sand e.V.
Freunde des Instituts für Massivbau der Technischen Universität Darmstadt e.V.
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HSE Technik GmbH
InformationsZentrum Beton GmbH
Ingenieurbüro Krebs und Kiefer
Ingenieurconsult Cornelius Schwarz Zeitler GmbH
Institut Wohnen und Umwelt
Klimaleichtblock GmbH
König und Heunisch Planungsgesellschaft mbH & Co KG
LCEE Life Cycle Engineering Experts GmbH
Liapor GmbH & Co.
Longlife-Treppen GmbH
LohrElement GmbH
MAPEI Betontechnik GmbH
Max Bögl Bauunternehmen GmbH
MEVA Schalungssysteme GmbH
OPTERRA Karsdorf GmbH
pakon AG, PreConTech e.K.
Ruffert & Partner
Schlagmann Poroton GmbH & Co. KG
Schöck Bauteile GmbH
sh minerals GmbH
solidian GmbH
Spenner Zement GmbH & Co. KG
Strabag AG
Syspro-Gruppe Betonbauteile e. V.
thyssenkrupp Carbon Components GmbH
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Xella Technologie und Forschungsgesellschaft mbH

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. Herbert Duda	Angewandte Baudynamik
Dipl.-Ing. Thomas Heß	Technische Gebäudeausrüstung I + II
Dr.-Ing. Gert Riegel	Strategisches Facility Management & Sustainable Design
Dr.-Ing. Eric Brehm	Risiko und Sicherheit im konstruktiven Ingenieurbau
Dr.-Ing. Georg Geldmacher	Massivbrückenbau und Traggerüste

Furthermore, we would like to thank the following persons for their lectures as well as for their commitment. Special thanks are owed to Dr.-Ing. U. Grziwa and Dr.-Ing. T. Kranzler, who held the lectures in the subjects of “Stahlbetonbau” and “Mauerwerksbau” during the research semester of Professor Graubner.

Stahlbetonbau
Dr.-Ing. Ulf Grziwa
Angewandte Baudynamik
Dr.-Ing. Markus Spengler
Fertigteilkonstruktionen
Dipl.-Ing. Mathias Tillmann
Dipl.-Ing. Alice Becke
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CARBON REINFORCED CONCRETE MEMBERS UNDER LONG-TERM LOADS
- PREPARATORY TESTS -

Redouan El Ghadioui, Larissa Krieger

As part of preparatory tests for a large-scaled research project to investigate the behaviour of carbon concrete under long-term loads, carbon reinforced concrete slabs were analysed in 4-point bending tests with regard to their load-bearing and deformation behaviour under static long-term loading. Here, two different carbon grids were investigated, which differed significantly in their impregnation material, their cross-sectional shape and their level of development. The carbon fibres of the grid X which is in development stage are impregnated with an aqueous film-forming dispersion (styrene-butadiene). The carbon rovings in warp direction have a nearly round cross-section. The grids labelled with an S are characterised by an epoxy resin impregnation and an oval roving form.

In a first series of tests, the load-bearing capacities were determined by applying short-term loads. Before the actual reinforcement failure occurred (as observed at the members with grids labelled with an X), the concrete slabs with the S-grids failed due to delamination. This longitudinal crack formation is amplified by the oval cross-sectional shape of the rovings.

Based on the tests for determining the load capacities, four concrete slabs were tested under static long-term loads with variation of the load intensities. The load level α can be understood as the quotient of the applied load to the previously determined load capacity. For the members with the X-grid, the load level was set at 50 %, 60 % and 70 %. The concrete member with the S-grid was loaded with a load level of 70 %.

In the diagram shown in Figure 1, the deformations determined in the centre of the concrete slabs are plotted over the load duration.

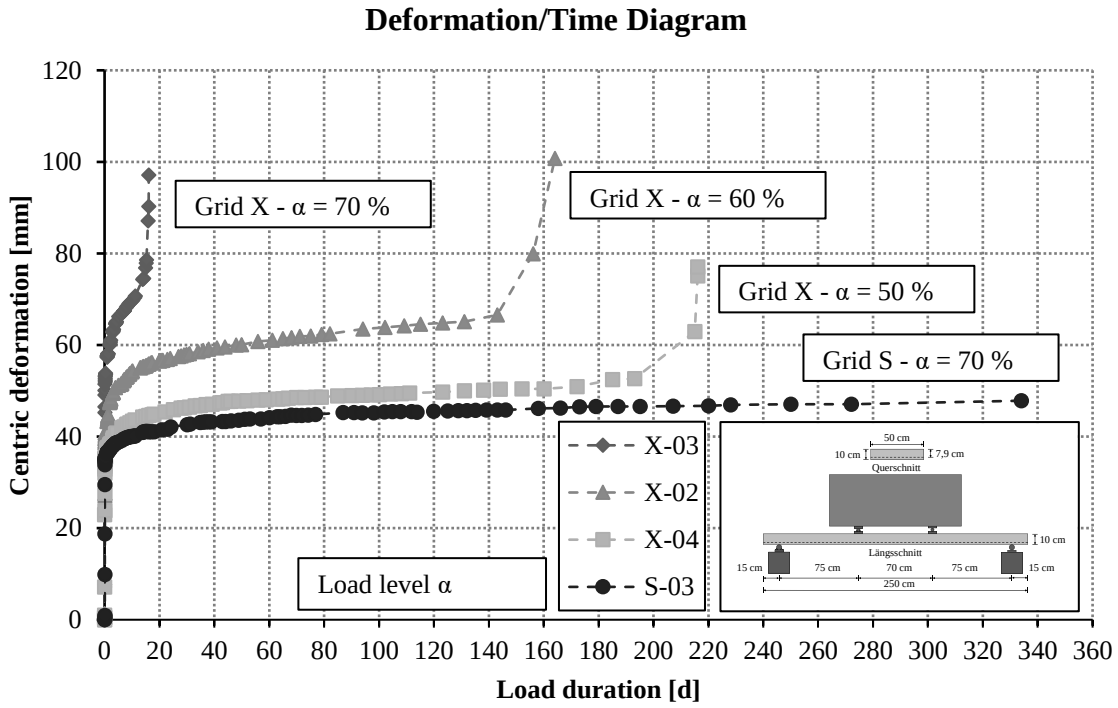


Figure 1: Deformation/Time Diagram

The members with the X-grids showed a concrete compression failure after 16, 165 and 216 days depending on the load level. At high levels of stress different creep phases (primary, secondary, tertiary) can be observed. In the last phase, the creep rate and thus also the microcrack growth in the concrete structure increase exponentially. There is a drop in strength of the concrete, which is much greater than the post-hardening. The member with the S-grid did not fail even after more than 300 days. It should be noted that due to the delamination that occurred in the load test for the slab with the S-grid, the absolute load and thus also the size of the creep-generating stresses of this long-term test are lower. The failure of the members with the X-grid is especially caused by the low processing quality of the grid (poor bond behaviour, poor impregnation) and the higher loads. Due to the poorer bond, slip increases at first, which reduces the compression zone height and thus increases the stresses.

BIAXIAL BENDING OF UNREINFORDCED CONCRETE AND MANSONRY COMPRESSION MEMBERS

Valentin Förster

In Germany, compression members made of concrete, such as columns and walls, are usually reinforced, whereas masonry members are unreinforced. This points out, that there is no need for reinforcement to ensure the load-carrying capacity, because even unreinforced compression members can carry significant bending moments. The avoidance of unreinforced concrete compression members is mainly due to the fact that simple design methods are only available for the two-dimensional planar case (compression with uniaxial bending) and not for the general three-dimensional spatial case (compression with biaxial bending). Bending moments about two axes do not only act because of the biaxial rotation of the adjacent components, but also because of uniaxial rotations about the weak axis (e. g. due to the deflection of the slab) in combination with horizontal loads in direction of the strong axis due to being part of the bracing system, see Fig. 1.

In order to enable a high utilisation of the existing load-bearing capacity, in (1) the load-carrying capacity of unreinforced compression members made of concrete or masonry under biaxial eccentric loading was investigated. With the determined moment-curvature-relationships, it was possible to derivate the load-bearing capacity of compression members with linear-elastic material behaviour without flexural tensile strength analytically. The analytical solution for the uncracked cross-section is also valid for the special case of linear-elastic material behaviour with the same compressive and flexural tensile strength, which is demonstrated by comparing the load carrying capacities with those of the existing design codes for steel and wood. In addition, a numerical model was developed, with which the approximation of the analytical model – the estimations of the shapes of curvatures – was successfully verified. Moreover, any non-linear material behaviour can be taken into account with the numerical model.

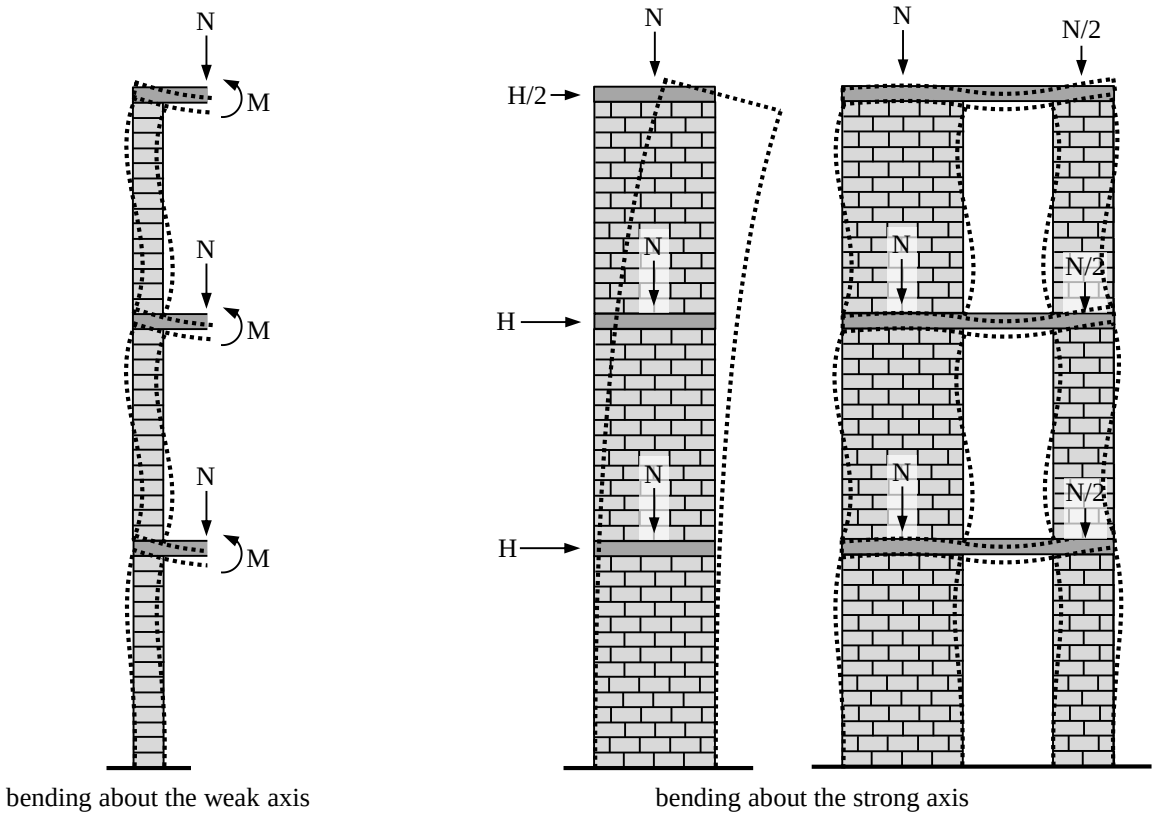


Figure 1: Exemplary bending moments about the weak and strong axis (1)

With comprehensive analytical and numerical calculations, a simple and practical design method was developed. Since the method approximates the load-carrying capacity of biaxially eccentrically loaded compression members by using the load-carrying capacity of uniaxially eccentrically loads compression members, the method can be integrated into existing design codes easily.

(1) Förster, V.: Tragfähigkeit unbewehrter Beton- und Mauerwerksdruckglieder bei zweiachsig exzentrischer Beanspruchung. Dissertation (submitted), Institut für Massivbau der Technischen Universität Darmstadt.

DETERMINATION OF MECHANICAL PROPERTIES OF BASALT FIBRE REINFORCED POLYMER BARS

Sebastian Hofmann, Tilo Proske

The use of fibre reinforced polymer (FRP) bar as reinforcement in concrete components is subject of current research projects at Institute of Concrete and Masonry Structures. In order to be able to design large-scale test specimens and to apply numerical calculations, precise knowledge of the mechanical properties of the FRP reinforcement is essential. However, there is still no standardised test setup or procedure in Germany and Europe to determine the mechanical properties of FRP reinforcement. For this reason, a suitable test setup has to be designed for performing tensile strength tests of FRP reinforcement.

Due to the low strength lateral to the fibre orientation, the clamping of the FRP reinforcement bars into the tensile testing machine is a great challenge. To achieve an appropriate load transfer, the bar is fixed in a plastic tube (d = 36 mm and l = 200 mm) with a filling material. The requirements of the filling material are, in addition to the transfer of the bonding forces, a good processability and cost-effectiveness. In order to find a suitable filling material, various materials - composite mortar (V1), methacrylic resin (V2), epoxy resin (V3) and fine grained concrete (V4) - were used in preliminary studies of a research project on the application of basalt fibre reinforced polymer bars for reinforced concrete. Sanded basalt fibre bars of 700 mm length and a nominal diameter of 6.0 mm and the mentioned filling materials were used. Load transfer was controlled by force at 3.0 kN/min while the strains were recorded with an extensometer in the centre of the bar.

First results of the tensile tests show that for both V1 and V4 bond failure of the anchoring occurred and thus no tensile strength of the reinforcement could be determined (see Figure 1). For V2 and V3, however, the sample could be loaded until rupture of approx. 1050 N/mm². The Young's modulus was determined to approx. 59000 N/mm² and is slightly above glass fibre reinforced polymer bars.

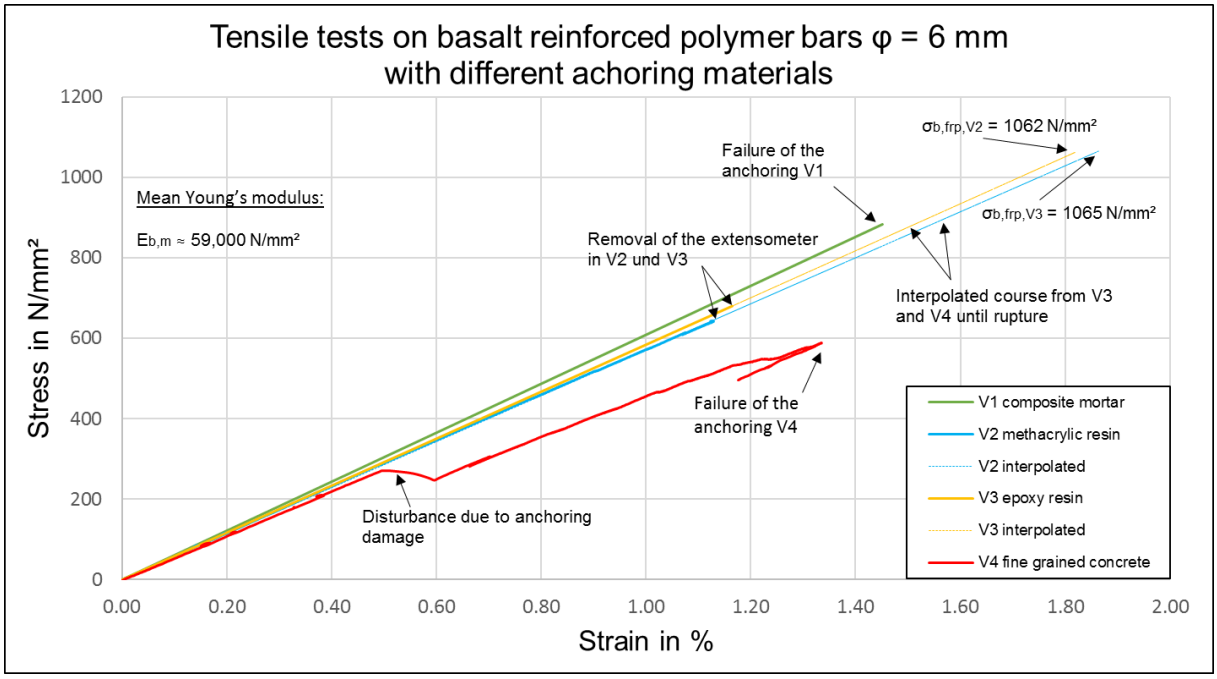


Figure 1: Stress-strain diagram of basalt fibre reinforced polymer bars with d = 6 mm

The stress-strain curves of tests V1 to V4 show the same slope, suggesting that the filling material did not affect the results on the Young's modulus. However, further investigations with other bar types and diameters, tube diameters and anchor lengths are needed to verify the results and optimise the experimental setup.

ANALYSIS OF THE METHOD FOR DETERMINING THE OUT-OF-PLANE BENDING MOMENTS OF MASONRY WALLS

René Mazur

During the review of Eurocode 6 part 1-1 for the design of masonry structures, the method given in Annex C for determining the out-of-plane bending moments for masonry walls due to rotation of a slab is currently being adapted. In this context the most important changes are the European-wide integration of partially supported slabs and the implementation of out-of-plane bending moments due to wind loads. Partially supported slabs are included in the new proposal in the same way as according to the current EC 6-1-1 in combination with the differing German regulations. The integration of the acting wind loads into the method according to Annex C is a significant change. Therefore, the results of the new proposal should be compared to those of the current German regulations in detail to avoid lacks of safety in the design.

For determining the out-of-plane bending moments of a masonry wall due to wind loads, the structural engineer usually has to choose a reasonable distribution. Here, full and partial restraint against rotation as well as hinged joints can be assumed on the top and bottom of a wall. For example, a split of the bending moment into $|M_{Wind}| = 1/16 \cdot w_{Ed} \cdot h^2$ at top, bottom and mid height of a wall is possible, assuming partial restraints at top and bottom of the wall. The bending moment at the mid height of the wall can be calculated by “hanging in” a square parabola between the top and the bottom. In the new proposal for Annex C, this currently usually used method is not excluded. But in addition, there is a further possibility of calculation, which could be useful especially for computer applications.

The following equation describes the new approach of the revised Annex C, where the symbols are unchanged compared to the current approach:

$$M_1 = -\frac{w_1 h_1^2}{4(n_1-1)} + \frac{\frac{n_1 E_1 I_1}{h_1}}{\frac{n_1 E_1 I_1}{h_1} + \frac{n_2 E_2 I_2}{h_2} + \frac{n_3 E_3 I_3}{l_3} + \frac{n_4 E_4 I_4}{l_4}} \left[\frac{w_1 h_1^2}{4(n_1-1)} - \frac{w_2 h_2^2}{4(n_2-1)} + \frac{q_3 l_3^2}{4(n_3-1)} - \frac{q_4 l_4^2}{4(n_4-1)} \right]$$

From the first term in the equation above, it can be seen that the bending moments due to wind loads on the top or bottom of a wall always have the values of fully restraint joints $M_{Wind} = 1/8 \cdot w_{Ed} \cdot h^2$ or $M_{Wind} = 1/12 \cdot w_{Ed} \cdot h^2$, depending on the assumed bearing conditions of the other joint. In the load term, the acting bending moment due to wind loads can be in- or decreased because of different story heights, wind loads or bearing conditions. Assuming identical story heights, Figure 1 shows an example of a comparison between the approach currently valid in Germany and the new draft. This example shows that the new proposal for Annex C leads to results which are within the limits of the current regulations. Finally, the new design model can be considered as safe. In some cases however, it may be still useful to apply the currently valid approach in order to have some flexibility in the design.

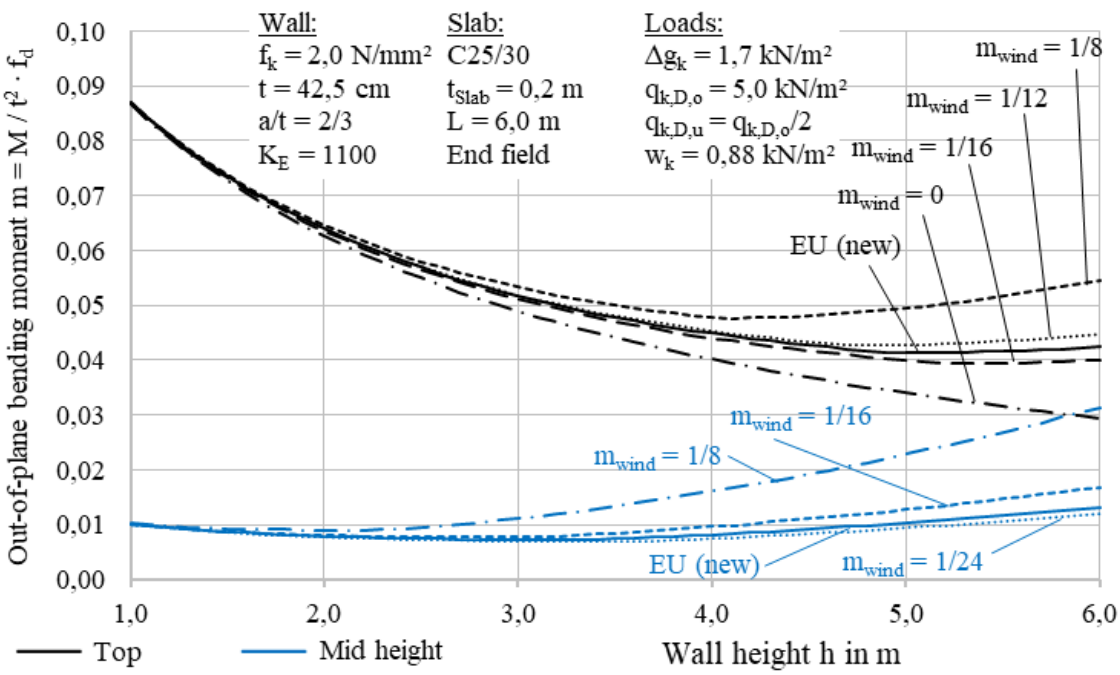


Figure 1: Exemplary comparison between EC6-1-1/NA Annex C and its new proposal

INFLUENCE OF SPATIAL VARIABILITY ON THE STATISTICAL DISTRIBUTION OF LOAD-BEARING CAPACITIES

Dominik Müller

At the Institute of Concrete and Masonry Structures, the reliability of masonry in compression is currently investigated. Since a masonry wall is made from single units and mortar layers, a significant spatial variability of material properties (= scatter within a member) exists. The general influence of spatial variability on the load-bearing capacity shall be demonstrated by an example. Within reliability theory, a member with spatial variability can be viewed as a system consisting of several elements. An exemplary idealised structural member shall consist of n = 10 imaginary elements, whose strengths scatter independently. The strength of a single element shall be normally distributed with a coefficient of variation of 20 %. Two ideal systems are investigated, which are the serial system (i.e. weakest link determines load-bearing capacity) and the parallel system, see Fig. 1. For the parallel system, two different element idealisations can be made. In the case of ideally ductile elements, the load-bearing capacity of the system results from the sum of the element strengths. In the case of ideally brittle elements, an element immediately fails when its strength is reached but the load can be further increased if the remaining elements can additionally resist the previous load of the failed element.

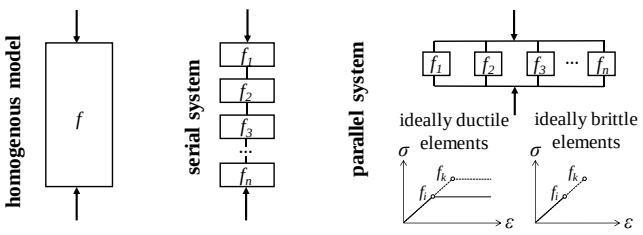


Figure 1: Idealisations of system and element

In comparison to a homogeneous model, the probability distribution of the load-bearing capacity considering spatial variability always shows a smaller variance, see Fig. 2. Except for the parallel system with ideally ductile elements, however, spatial variability also causes a reduction in the mean value of the load-bearing capacity. For structural reliability, the lower quantile values and thus the area under the left tail of the probability distribution are important. Therefore, depending on the idealisation of the system and the elements, spatial variability can have a positive (parallel system with ideally ductile elements), negative (serial system) or negligible influence on structural reliability.

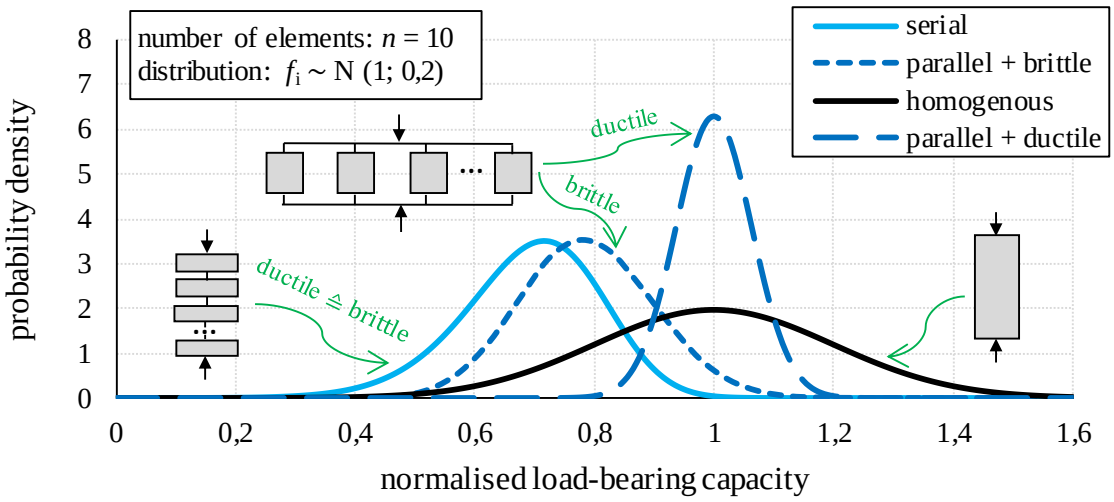


Figure 2: Probability distribution for different idealisations

The reliability-related behaviour of a real masonry wall lies in between the presented idealisations. Which idealisation is most suitable depends on the failure mode (compression failure or stability failure), the length of the wall and the stress-strain relationship of the material. Based on these input parameters, mixed systems with more realistic element behaviour can be developed and subsequently used in reliability analyses.

(1) Müller, D., Förster, V., Graubner, C.-A.: Influence of material spatial variability on safety factors for masonry walls in compression. European Journal auf Masonry 21 (2017), pp. 209–222.

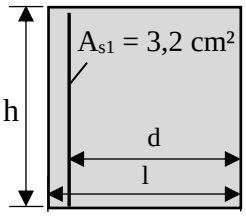
COMPARISON OF DIFFERENT DESIGN APPROACHES FOR DETERMINING THE SHEAR RESISTANCE OF REINFORCED MASONRY WALLS

Benjamin Purkert

An economic design of reinforced masonry is not possible in Germany due to the nationally determined partial safety factor of $\gamma_M = 10$. Against the background of the currently running systematic review of the European design code EN 1996-1-1, the question comes up whether this attitude should be maintained or if the final draft can resolve the safety concerns of the German Standardization Committee – especially regarding the shear resistance.

For this reason, the design approaches for determining the shear resistance of reinforced masonry walls given in the final draft of EN 1996-1-1, which was spread in the Standardization Committees in November 2017, are compared to the verification procedures of other design codes. Therefore, beside the new draft and the current version of EN 1996-1-1, the Australian Standard AS 3700-2011, the Canadian Design Standard S304-14 as well as the American Building Code TMS 402 were compared to each other and additionally, a design proposal of Ernst (1997) developed in his dissertation is taken into account.

The basis of the comparison is the wall shown in Figure 1. The shear resistance is calculated on the assumption, that the reinforcement is always used to full capacity. Therefore, the maximum bending moment, which increases with higher compressive normal force, is taken as basis. Beyond that, it is assumed, that all vertical openings in the masonry bricks are fully filled with grout, so that the complete width of the cross-sectional area can be taken into account in the shear design. The partial safety factor for masonry is chosen to $\gamma_M = 1{,}70$ in calculating the shear resistance according to EN 1996-1-1.



size:	**strength**:
h = 2,75 m	f_k = 5 MN/m²
l = 2,0 m	f_d = 2,94 MN/m²
t = 0,24 m	f_{yk} = 500 MN/m²
d = 1,75 m	f_{yd} = 435 MN/m²

Figure 1: Input for the calculation of the shear resistance

As it can be seen from Figure 2, the load capacities show a wide variation in parts. There is a good accordance between the Canadian Standard and the proposal of Ernst (1997), if the dowel effect of the vertical reinforcement is neglected. If this effect is considered, the shear resistance according to Ernst (1997) is approximately doubled. In contrast, the results according to Eurocode 6 conform in most instances with those according to the American Design Standard, especially regarding low vertical loads, and both codes result between the two approaches of Ernst. The Australian Standard provides the highest shear resistance independent of acting normal force and bending moment. In summary, it is not possible to give a distinct conclusion on the quality of the design procedure of EN 1996-1-1.

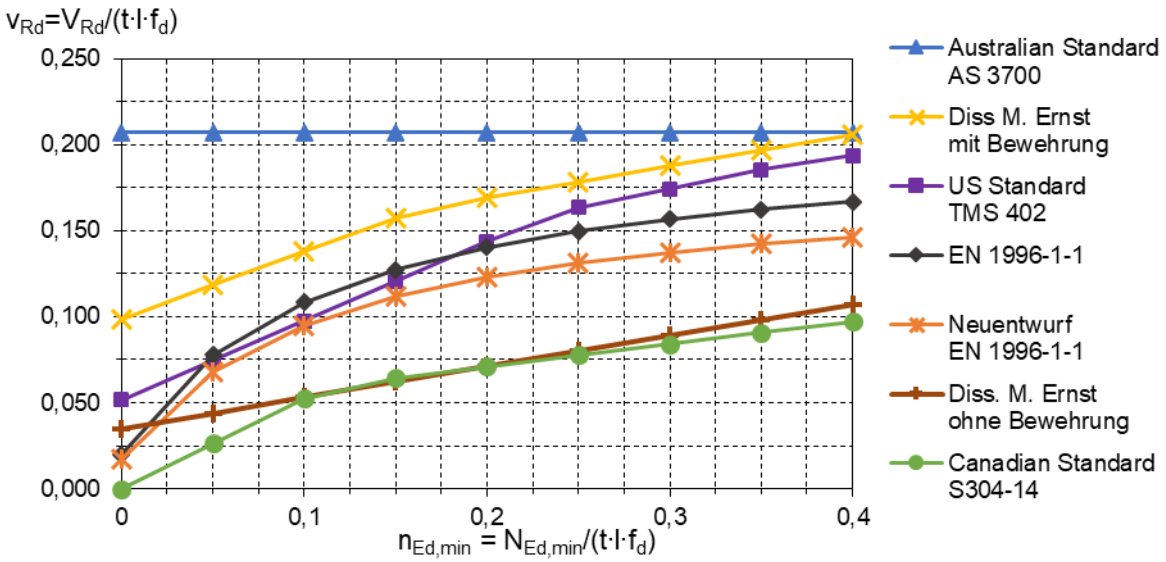


Figure 2: Comparison of the shear resistances of different standards

Ernst, M (1997): Untersuchungen zum Tragverhalten von bewehrtem Mauerwerk aus Hochlochziegeln. Fortschr.-Ber. VDI Reihe 4 Nr. 137. VDI Verlag Düsseldorf

SHEAR RETENTION FACTOR OF CRACKED CONCRETE

Ngoc Linh Tran

The nonlinear behaviour of concrete structures is mainly due to the development of concrete cracks. After cracking, the forces in concrete members can be transferred over cracks through aggregate interlock. An increase of crack opening will reduce the normal and shear stresses transferred over the crack. While the concrete tension softening can be well described as a function of crack opening w according to Hordijk (1991), the shear softening of concrete is more difficult to be exactly determined because the shear stiffness does not only depend on the crack width w but also on the shear slip s. Based on experimental results the relationship between s and w is described according to Kolmar (1985) as $s = 1.4 \cdot w^{1.2}$ for normal strength concrete and $s = 1.87 \cdot w^{1.4}$ for high strength concrete. This shows that the shear retention factor also depends on the concrete strength. Considering the influencing parameters of concrete including elastic modulus E_c, maximum aggregate size a_g, concrete strengths f_c and f_{ct}, a new formula for shear retention factor β is proposed in this paper, which is formulated by Eq. (a).

$$\beta = \frac{1}{1 + c \cdot \left(w / l_{ch} \right)} \tag{a}$$

Here, the characteristic length is defined as $l_{ch} = G_F E_c / f_{ct}^2$ according to Hillerborg et al. (1976) and c is a constant, which is determined according to experimental results. The fracture energy is calculated according to Marí et al. (2015) as $G_F = 0.028 \cdot f_c^{0.18} \cdot a_g^{0.32}$ N/mm. In this study, the factor c is chosen as 20000 based on experimental results of Shinohara (2001), see Fig. 1. The big advantage of the new formula is that through only the characteristic length l_{ch} many influencing parameters are taken into account.

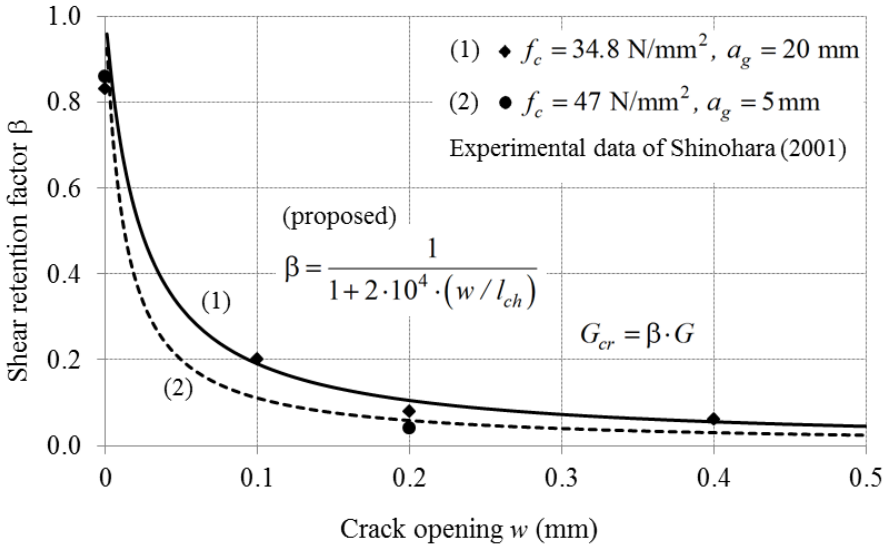


Figure 1: Decrease of shear stiffness with increasing crack opening

The proposed formula for the shear retention factor can be used for calculating the shear strength of reinforced concrete members without shear reinforcement.

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THERMAL SEPARATION OF REINFORCED CONCRETE WALLS

Jochen Zeier

A further improvement of the building envelope with regard to heat transfer is required in new buildings, because of the steadily tightening of the Energy-Saving Ordinance (EnEV). This leads to an increasing influence of thermal bridges on the overall heat loss of the building. An avoidance or reduction of these heat bridges can significantly contribute to an increase in the quality of buildings and thus to the future requirements of energy-efficient construction (Fig. 1). For thermal separation of reinforced concrete connections, which are mainly subjected to bending and transverse forces (balconies), products from different manufacturers are available on the market. For columns under predominant compression, the scientific foundations have already been researched as part of a research project at the Institute of Concrete and Masonry of TU Darmstadt. Thus, the connection of the pressure-loaded wall remains the thermal bridge, where no corresponding solution is present.

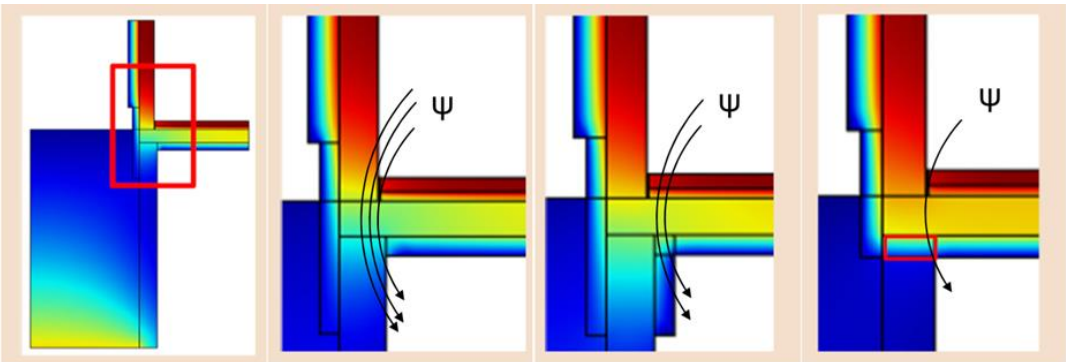

Figure 1: Temperature distribution in a wall-slab-connection

The aim of the research project is the development of a structural element which allows sufficient thermal decoupling of reinforced concrete walls (in the area of cold outside air) from reinforced concrete slabs (warm interior) and at the same time being capable to transfer high normal forces as well as to withstand large temperature changes. The main application area is seen in residential and office buildings with underground car parks.

In the theoretical part of the project, the structural requirements for column connections were first compiled. Materials identified by means of a literature search were evaluated on the basis of static, physical and economic criteria, while lightweight concrete and ultrahigh-strength concrete (UHPC) proved to be suitable materials. Based on these materials, basic variants for load transfer have been developed and compared.

An essential aspect of this research project is the determination of the requirements resulting from the deformation of the outer wall compared to the slab due to temperature changes. The temperature of the wall follows the temperature of the outside air, whereas the temperature of the ceiling due to the insulation always corresponds to the almost constant interior temperature.

In the experimental part, an extensive test program is used to analyze the bearing behavior with regard to the horizontal forces resulting from the deformation of the wall in relation to the slab. The goal is to achieve the greatest possible load-bearing capacity of the joint between the element and the wall or slab.

Furthermore, a FEM model for the numerical analysis of the structural behavior of the wall-slab-connection is developed and calibrated on the basis of the test results. Extensive parameter studies were carried out using this FEM model. Based on this, a reliable prediction of the failure load is made possible by using the proposed design concept.

The project was thankfully supported by Schöck Bauteile GmbH with know-how and material supplies.

SHRINKAGE OF CONCRETE MADE OF LIMESTONE-RICH CEMENTS

Moien Rezvani

Cement industry (mainly production of Portland cement clinker) is responsible for about 6% of worldwide CO_2 emission. Reduction of the Portland cement clinker and replacement with limestone in limestone rich cements is detected as one of the most efficient approaches to reduce the environmental impacts through concrete manufacture. Concrete made of cement with 50 wt.-% lime-stone and a reduced water-cement-ratio of 0.35 could exhibit sufficient fresh and hardened properties and a significant CO_2 cut-off up to 25% compared to conventional concrete [1]. However, long term creep and shrinkage of concretes made of such limestone cements with high limestone contents was observed to be significantly dependent on the content and the quality of limestone [1].

Within a research study, drying shrinkage, autogenous shrinkage and carbonation shrinkage behaviour of hardened cement paste and concrete made of limestone rich cements with limestone contents up to 70 wt.-% were analysed. It was observed that the shrinkage of concretes made of high limestone contents is strongly affected by the chemical-mineralogical properties of limestone, whereas the influence of methylene blue value was the most significant.

Based on the experimental findings, thermodynamic laws and mechanics of the porous materials, a multi scale model is developed to predict the drying shrinkage of hardened cement paste and concrete as a function of content and chemical mineralogical properties of limestone [2]. Prominently, this model considers capillary and disjoining pressure as the main shrinkage mechanisms (see Figure 1).

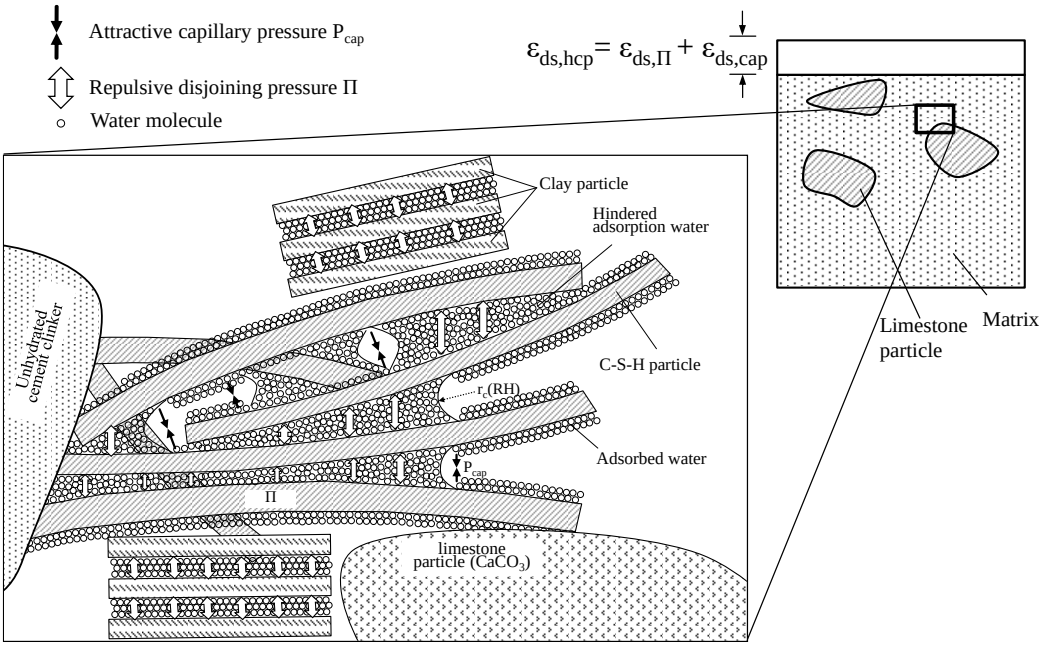

Figure 1: Illustration of the repulsing disjoining pressure and attractive capillary pressure in the matrix

Further on, the applicability of the current DIN EN 1992 1 1 for predicting the shrinkage of concretes with high limestone contents was evaluated. Based on the conducted evaluation and the developed model, a recommendation for adaption of design model for concretes made of limestone-rich cements is proposed as a function of the content and the chemical-mineralogical properties of limestone.

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DIFFUSION OF CO_2 IN CLINKER-REDUCED CONCRETES

Sarah Steiner, Tilo Proske

The production of Portland cement clinker is associated with high environmental impacts. Therefore, the development of clinker-reduced cements and concretes is aim of current research. Substitution of Portland cement clinker by limestone is a promising way to decrease the environmental impact of concrete. However, higher limestone contents can negatively affect the durability of concrete, especially the carbonation resistance (1). This is mainly due to the lower amount of phases such as Portlandite, C-S-H phases and Ettringite which are produced during hydration and can bind CO_2. On the other hand, a reduction of the water-cement-ratio can increase the resistance of concrete against the diffusion of CO_2 and therefore improve the carbonation resistance. In order to optimize the mix design of eco-friendly concretes, further research in the field of gas diffusion is necessary.

To evaluate the resistance of concrete against CO_2 diffusion, an experimental set-up for diffusion measurements was developed. The test device consists of a Plexiglas cylinder and a CO_2 sensor which is placed inside the measuring cell (see Fig. 1 (A)). At the top of the cell a disk-shaped concrete sample is placed, which should be fully carbonated in advance.

Within preliminary studies, various concretes with w/c-ratios of 0.30 to 0.75 were analyzed. The cement (c) is composed of ordinary Portland cement CEM I 52.5 R and different amounts of ground limestone (LL). The limestone content of the cement varies from 0 to 60 wt.-%. The samples were cured under different CO_2 concentrations (400 ppm up to 100 vol.-% CO_2) to investigate the influences of the CO_2 concentration on the structure formation during carbonation. The measuring cell has been placed in a CO_2 chamber with a constant CO_2 concentration of 100 vol.-%, temperature of 20 °C and 65% R.H. Reduced CO_2 concentrations of 2 and 20 vol. % has been applied in further studies. In order to avoid an additional water vapor

diffusion, a constant relative humidity of approx. 65% was realized inside the measuring cell by a saturated salt solution (NH_4NO_3).

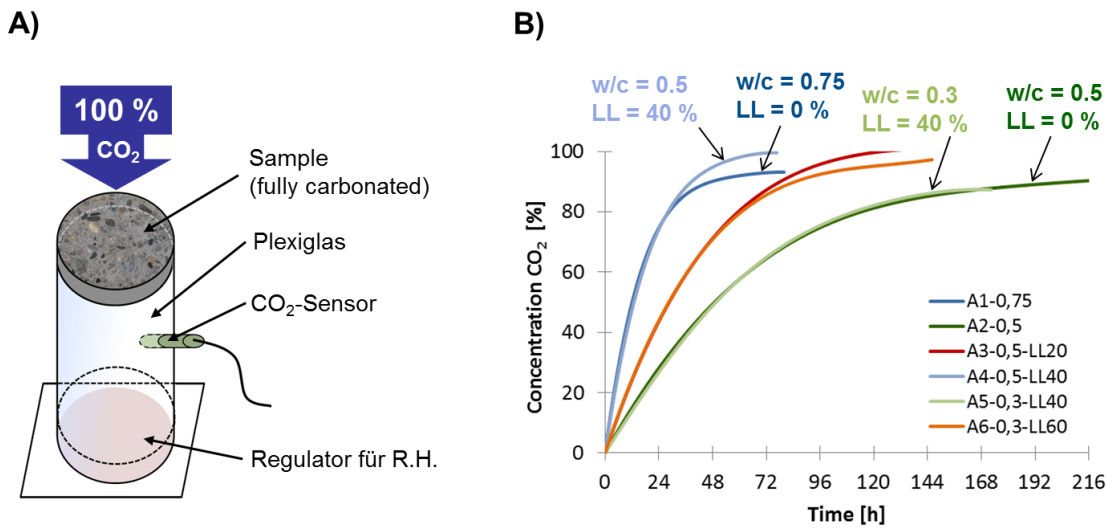

Figure 1: (A) Experimental set-up for CO_2 diffusion measurements. (B) time-dependent CO_2 diffusion inside the measuring cell.

Figure 1 (B) shows the development of the CO_2 concentrations inside the measuring cell for selected mixtures during one test cycle. The ambient CO_2 concentration was approx. 100 vol.-%. Based on the CO_2 gradient of the curves, the diffusion coefficients for each sample was calculated using the second Fick´s law. The results show that a substitution of Portland cement clinker by limestone, associated with a reduction in water content, can achieve similar diffusion resistances compared to pure Portland cement concretes or concretes with low limestone contents. For example, the mix with a low limestone content of 20 wt.-% and a w/c-value of 0.5 (A3-0.5-LL20) shows a diffusion coefficient of $2.7 \cdot 10^{-8}$ m^2/s. In comparison, the concrete sample with a higher limestone content of 60 wt.-% and a reduced w/c-value of 0.3 (A6-0.3-LL60) reached a similar diffusion coefficient of $2.8 \cdot 10^{-8}$ m^2/s.

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EFFICIENCY BENEFITS DUE TO ENERGY DATA METERING AND ANALYSIS

Achim Knauff

The detailed accounting of expenditures becomes more and more important for companies in order to act economically and to increase the profitability. In particular, the field of energy data analysis offers the opportunity to identify optimization potentials, so that saving measures can be implemented and current energy costs significantly reduced. Identified and realized saving measures have an enduring impact. Hence, every further optimization potential found and realized will result in a considerable cumulation of reduced costs for years.

Energy data analysis includes as a first step the plausibility check of the energy and medium consumption to identify inefficient operational states. It should be noted that recorded conspicuous consumption data are past events, so that consumption data can be reactively dealt with only. Therefore, major added value is achieved if the past operating states are used strategically to proactively uncover future optimization potentials. Thus, the continuous metering and analysis can result in optimization potentials from i) the comparison of the consumption of a supply area with the associated use, ii) controlling the operation time of plants versus the working hours, or iii) the efficiency monitoring of individual plants and plant systems.

For example, the advantage of energy data metering is illustrated by the methodical analysis of the energy generation costs of an energy interconnection system for heating and cooling. Energy interconnection systems are used in particular in buildings, complexes and urban districts, which have a simultaneous need for multiple forms of energy. By means of an adequately detailed energy data metering, the sources and sinks of the individual forms of energy can be continuously recorded and analyzed with regard to the resulting energy generation costs. Aim is to distribute the demand in the future optimally among the available generators.

To illustrate this, Figure 1 shows, on the one hand, the sum of the energy generation costs for heating and cooling by means of a chiller ice storage combination driven by cooling demand. On the other hand, the distribution of the heat demand between the recovery of the waste heat of the chiller for heating purposes and the backfeed of the heat generator peak loads is shown. When the demand for cooling is low, the system switches between operating modes "A" unloading and "B" loading the ice storage. If the cooling demand increases, the chiller operation takes place without the participation of the ice storage in operating mode "C".

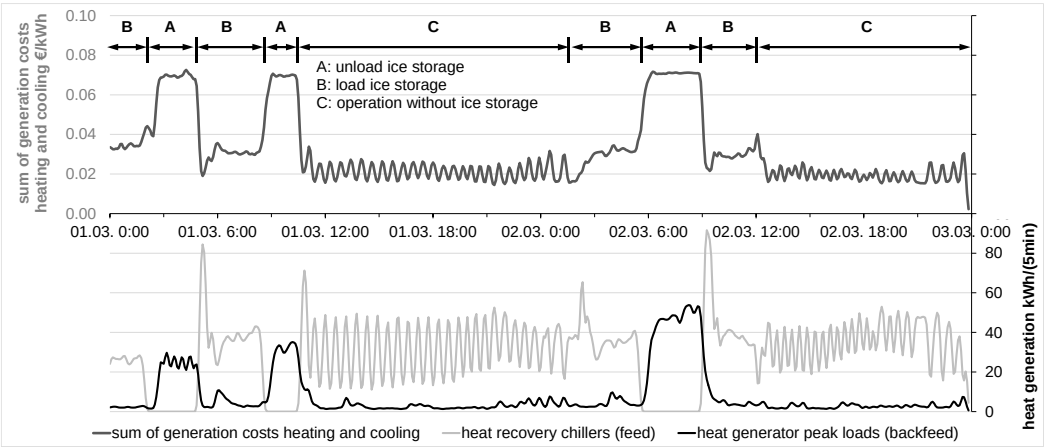

Figure 1: Analysis of the energy generation costs of an energy interconnection system

The advantage of energy interconnection systems can be seen in operating modes "B" and "C" when both, the heating and the cooling, generated by the chiller can be used. Thus, the energy generation costs tend to the lower energy price, which results from the chiller efficiency assessed electricity price. On the contrary, the energy generation costs during the discharge of the ice storage in the operation mode "A" tend to the higher energy price of the heat generation peak loads. An optimization potential consists of extending the operating mode "C" without the participation of the ice storage within the scope of the technical possibilities in the area of low cooling demand.

ECOLOGICAL AND ECONOMIC ASSESSMENT OF RENEWABLE ENERGY SUPPLY OPTIONS FOR RESIDENTIAL DISTRICTS

Claudia Weißmann

In the context of the menacing climate change integrating renewable energy sources in the energy supply of buildings is a major target of the federal energy concept. Likewise, greenhouse gas emissions may be reduced in the long term. At the same time it has to be ensured that this transformation of the German energy supply system does not lead to essential economic disadvantages for the society. However, it is currently unclear which renewable energy technology provides the greatest potential regarding these requirements. Especially if not a single building but whole urban district concepts are considered because interconnected as well as non-interconnected supply options have to be observed in this case. Regarding this topic a scenario analysis of an exemplary residential district with varying technology equipment has been conducted. The results of this scenario analysis are presented in the following.

The exemplary residential district consists of 50 single family houses with an envelope according to the EnEV 2016 standard. Table 1 visualizes the technology equipment of the analyzed scenarios. In the baseline scenario the buildings are supplied by a condensing gas boiler and a connection to the public electric grid.

Table 1: Overview – Scenario technology equipment

Scenario	Technology equipment	Interconnection
Base	Condensing gas boiler	None
A.1	Brine/water heat pump	None
A.2	Brine/water heat pump, photovoltaics	None
A.3	Brine/water heat pump, photovoltaics, battery	District electrict grid
B.1	Condensing gas boiler, solar heat	None
B.2	Condensing gas boiler, solar district heating	District heating
B.3	Condensing gas boiler, solar district heating, CHP	District heating and electric grid

Scenario group A focuses the renewable electricity supply while in group B the heat production from renewable energy sources will be analyzed. The energy flows of the residential district are described by load profiles which had been previously determined by simulation or deduced from monitoring data. For the ecological evaluation the life cycle assessment method according to DIN EN ISO 14040 is applied. The global warming potential (GWP) is calculated as the key indicator which also includes the production and the disposal of the technical equipment. The economic key figure is the net present value (C_0) which is calculated within the framework of a life cycle costing approach for every supply option. The applied methods are described in detail in (1). Figure 1 shows that all renewable energy scenarios are assessed as ecologically better than the baseline scenario, while the A-scenarios are more advantageous than the B-scenarios. Furthermore, the B-scenarios are assessed as economic worse than the baseline scenario. Apart from that, the figure illustrates that interconnected scenarios are always economically worse but ecologically better assessed than non-interconnected scenarios of the same group (see A.1, A.2 vs. A.3 or B.1 vs. B.2, B.3). Finally, the conducted analysis shows that from the ecological perspective as well as from the economic perspective supply concepts with brine/water heat pumps and photovoltaic systems should be currently preferred in residential districts.

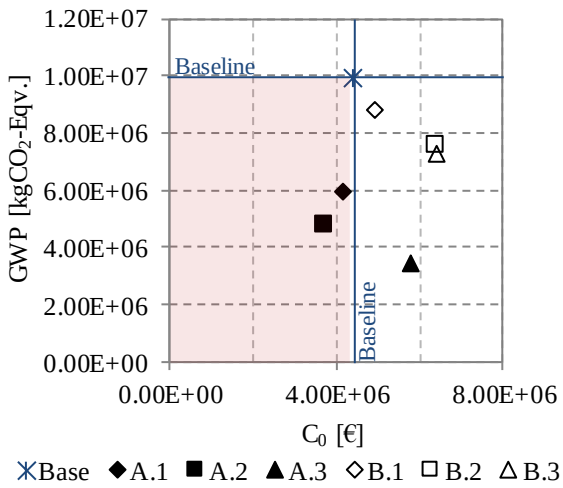

Figure 1: Comparison of the ecological and economic scenario assessment

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POTENTIAL FOR OPTIMIZATION OF THE INSTALLED CAPACITY IN DISTRICT HEATING SYSTEMS

Claudia Weißmann, Patrick Wörner

In district heating systems, the installed capacity of the central heat generating plant is designed to be capable of covering the district's maximum requested heating load at any time. A high diversity of energy demand profiles within the district may balance the impact of individual peak loads and therefore lower the installed capacity, which leads to optimizations in energy efficiency and investment costs. The rationale behind this assumption is depicted in Figure 1: Having a multitude of buildings within a district, the time steps in which their maximum loads appear do not usually coincide. As a consequence, the conjoint maximum heat demand of these buildings as a group (CS peak load) is expected to be lower than the simple sum of all individual peak loads.

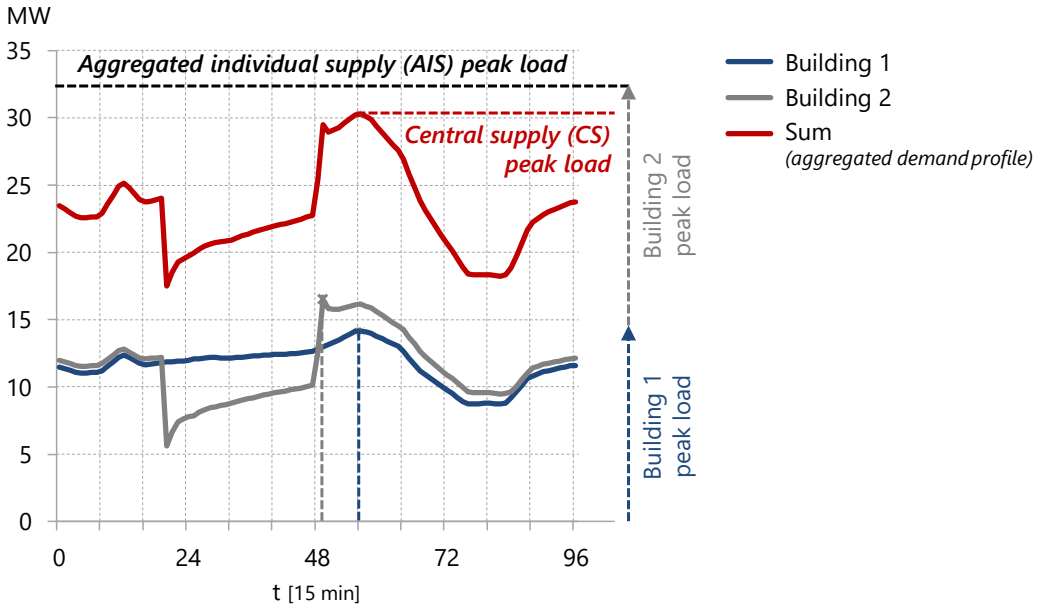

Figure 1: Aggregated individual supply (AIS) peak load and central supply (CS) peak load

In order to quantify the theoretical benefit of district heating systems in terms of installed capacity, a *peak load ratio (PLR)* index gives the percentage reduction in the district's peak load compared to the aggregated peak loads of all individual buildings. In this way, the influence of single building and occupant related characteristics on diversity and the residential district's overall heat demand profile can be investigated, respectively. The results were presented at the international *IBPSA Building Simulation 2017* conference in San Francisco. (1)

Based on 144 distinct load profiles, which were created using the dynamic building simulation software IDA ICE, the PLR index is employed on fictional test districts consisting of these profiles. An exemplary combination of load profiles achieves a PLR index of 15 %. Given a district heating system, this implies a reduction of the overall installed capacity by the same amount compared to a case in which each building features a separate facility to generate heat. Further analyses show that the PLR generally increases if buildings compliant with current energy saving standards are added to a district with older buildings or if multi-family houses join a district of single-family houses. Furthermore, the PLR increases in most cases if buildings with different user behavior are added. Above that, temperature controls, e.g. setbacks during night hours, have a decisive impact on load diversity. In order to trade off the described benefit of reduced installed capacities against the practical disadvantage of heat distribution losses, the results of the PLR analysis are applied to a district heating simulation model. The outcomes show that especially districts with a high number of energy consumers and buildings constructed according to the latest building energy standards have the potential to take the advantage of load diversity. Still, heat losses within the piping network cannot be neglected. (2)

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INTEGRATION OF THE ENERGY SECTORS IN THE BUILT ENVIRONMENT USING POWER-TO-GAS

Patrick Wörner

By the year 2050, at least 60% of Germany's gross final energy consumption shall be covered by renewable energies. While the expansion of regenerative electricity generation is progressing, the renewable share in the heating and transport sector, which are both heavily characterized by fossil fuels, is currently only 13 % and 7 %, respectively. (1) Besides that, the demand for electricity storage both centrally and decentrally will rise massively with further expansion of renewable electricity generation from fluctuating solar and wind power. Due to the circumstance that buildings act as a decisive interface between the electricity, heating and transport sector, energy generation and consumption related to buildings and districts are becoming the focus of future energy systems, because they offer numerous starting points to utilize electricity surpluses and to enhance the share of renewables.

In this context, *power-to-gas (P2G)* represents a promising technology, as it provides not only a wide variety of utilizations but also a long-term storage option for electricity. Moreover, P2G systems allow to compensate forecast errors in terms of grid efficiency and are suitable as flexible consumers for the provision of operating reserves. At the beginning of a whole process chain, hydrogen (H_2) is produced through renewable electricity surpluses using water electrolysis:

$$2\,H_2O \rightarrow 2\,H_2 + \,O_2 \qquad \Delta H_R^0 = +572\,kJ/mol \qquad \text{(a)}$$

With the addition of carbon dioxide (CO2), e.g. from biogas plants, sewage treatment plants or carbon capture facilities in fossil fuel power plants, a chemical reaction to methane (CH_4) is possible in a following step:

$$4\,H_2 + CO_2 \rightarrow\ CH_4 + 2\,H_2O \qquad \Delta H_R^0 = -165\,kJ/mol \qquad \text{(b)}$$

Subsequently, methane can be fed into the public gas grid without limits, thus making full use of the existing supply infrastructure, while the feed-in of hydrogen is subject to a limitation of 2-5 %. Both gases can be compressed and stored in tank containers or cavern storages for several months until they are converted to electricity in times of excessive energy demand. During the conversion of H_2 in fuel cells or the combustion of CH_4 in combined heat and power plants, heat is released as well, which can be leveraged in order to cover the space heating and hot water demand of buildings. In the case of methane, an emission-free cycle comparable to the redox reaction of hydrogen is imaginable if the emitted CO_2 is stored and later added to the methanation reactor. (2)

The P2G technology is still in the stage of development and being explored in a number of demonstration projects, notably with regard to the improvement of single components. In practice, however, the low cost efficiency due to high specific investment costs as well as the lack of exemptions from surcharges prevents the breakthrough of synthetic gases. Currently, only the transport sector offers starting points for a market launch, because relatively high sales prices can be achieved due to mineral oil taxes. (3) An increased use for mobility would eventually lead to cross-sectoral optimizations of P2G's overall efficiency, though. Furthermore, combined solutions should be tested in order to use waste heat the most efficient way, since already during electrolysis and methanation certain temperature levels arise which qualify for an integration into district heating systems. In this way, the linkage of buildings within quarters hold enormous synergy effects.

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