University of Stuttgart
Institute of Construction Materials

IWB

Newsletter 18/1

„Fastening Technology and Strengthening“

18/1

Fastening Technology
Reinforced Concrete Construction
Structural Strengthening
Experimental Research
Numerical Analysis
Approval Testing

Shear tests on anchors in masonry

Quelle: Stipetic, M.: Zum Tragverhalten von Injektionsdübeln in ungerissenem und gerissenem Mauerwerk, Stuttgart, Univ., Diss. 2018

The positive feedback on our first Newsletter 17/1 (http://www.iwb.uni-stuttgart.de/download_g/Newsletter_17_1.pdf) published in September 2017 parallel to our Symposium ConSC 2017 encouraged us to continue providing all our interested partners with current information on activities of our department ‚Fastening Technology and Strengthening , at the Institute of Construction Materials, University of Stuttgart.

In this Newsletter 18/1 you will find news on research topics in the fields of fastening technology, reinforced concrete construction and numerical simulation as well as a retrospect to ConSC 2017. A selection of current research projects is presented and described in short to give an impression on our actual challenges.

A testing laboratory is only as good as its staff and equipment. To maintain the high standards of our laboratoy, we continously invest in the upgrade of the equipment and further education of our highly-qualified staff. Therefore we are glad to present our new achievements.

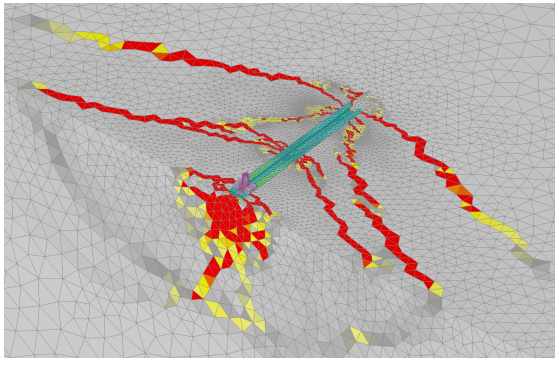
Thank you for taking the time reading this Newsletter. Enjoy!

Research Competence

Fastening technology

Knowledge on white fields in the design of fastening to concrete and masonry and cooperation with our partners enables us to a steady stream of ideas for the generation of new research projects. With the excellence and strength of our relationship with governmental and international industry partners we managed to get many projects realized. In the following a selection of current projects is given:

- Fatigue behavior of fastenings
- Anchor channels, design
  - pry-out failure of anchorages
  - blow-out failure
  - loading in the direction of the channel axis



- Adhesive anchors, long term effects
- Design of anchorages beyond the scope & current codes
- Post -installed rebar systems unter seismic loads
- Anchorages under Fire
- Pryout failure of anchorages
- Anchorages in new materials
- Fastenings solutions of strengthening
- Design of structures with post-installed rebar systems
- Gluing for fastenings to concrete
- Anchorage with supplentary reinforcement

The overall objective of this research work is the translation of the findings into international prequalification and design procedures facilitated by the membership of our staff in international standardization committees.

ConSC 2017

More than 200 experts from 29 countries attended the ConSC2017 Symposium to meet and interact in Stuttgart from September 27 to 29, 2017. They used this 3rd International Symposium on Connections between Steel and Concrete as forum to exchange latest knowledge in research, technology, code development and practice in the fields of connecting structural/non-structural components to the structure with anchors, reinforcement embedded in concrete or steel-concrete composite construction. Furthermore exhibition stands showed the actual innovations in products and software.

The attractive program with parallel sessions on design, experimental studies, numerical analyses, special applications, code development etc. was accompanied by a special session with invited lectures to honour Rolf Eligehausen‘s 75th birthday. This special event was a reunion of former companions, colleagues and PhD students exchanging not only professional but also personal reminiscences.

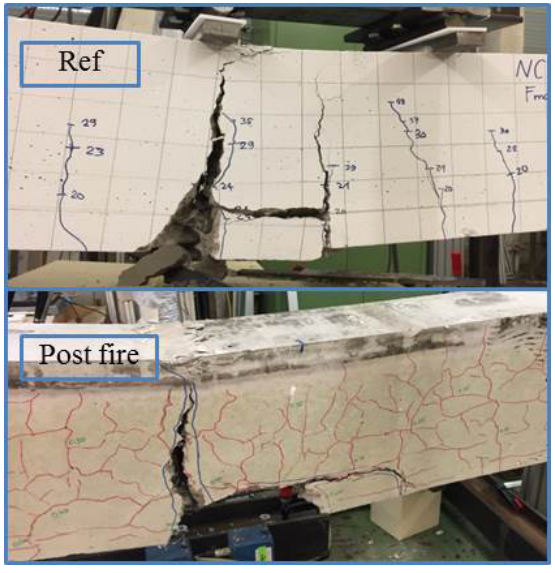
The discussions indicated that since the last Symposium on ‚Connections between Steel and Concrete‘ one decade ago outstanding progress in the understanding of the fundamental principles underlying anchorage to concrete and composite structures was achieved. Concurrently, there has been rapid growth in the development of sophisticated new products, as well as codes to regulate their use. Modern technology is increasingly employed in the design, execution and retrofit of engineered structures.

The more than 120 high quality research papers along with the keynote addresses and invited lectures presented at ConSC2017 can be downloaded from:
https://elib.uni-stuttgart.de/handle/11682/9362

Research Competence

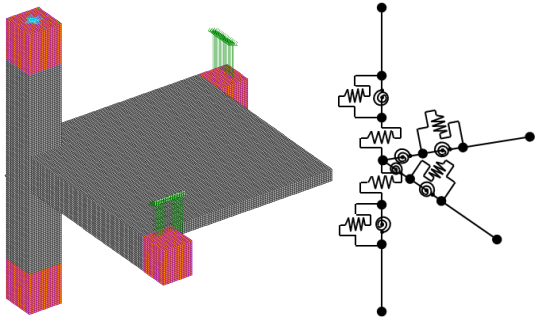
Reinforced Concrete Construction and Structural Strenghtening

The prime focus of the department of “Innovative strengthening methods with fastenings” at IWB is to perform research for development of the assessment methods and strengthening techniques for reinforced concrete structures. The experimental, numerical and analytical research work targets the (i) assessment of performance, and (ii) development of strengthening methods, for reinforced concrete structural elements, sub-assemblies and structures against extreme hazards such as earthquakes, fire, impact as well as against chronic hazards such as corrosion.



Some of the typical problems being targeted include:

- Bond between reinforcement and concrete
- Behavior and modeling of anchorages used in seismic strengthening
- Behavior and strengthening of RC members under fire
- Performance assessment and strengthening for life enhancement of corrosion affected beams
- Seismic performance assessment and strengthening of beam-column joints
- Seismic behavior and performance of structural sub-assemblies formed using post-installed reinforcing bars
- Development of anchorage solutions to connect seismic strengthening elements
- Strengthening of reinforced concrete elements using fiber reinforced polymer composites
- Performance of structural elements made using fiber reinforced concrete
- Dynamic fracture of concrete and reinforced concrete



The research work is supported through national and European funding organizations as well as through industry. An equal amount of emphasis is laid on the experimental and numerical work with an aim to develop engineering models and solutions that could be implemented in practice to solve the complex problems. The solutions developed are disseminated to the community through regular publications in peer-reviewed journals and International conferences.

Current Research Projects

Fastenings in special concretes

N. Vita, A. Sharma, J. Hofmann

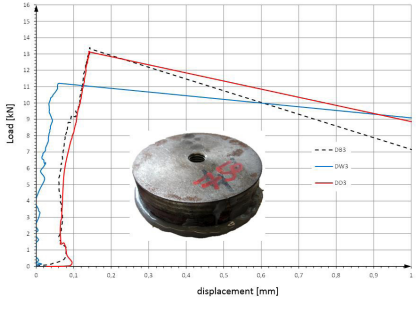
The design of anchorages in concrete is based on the CCD-Method given in ETAG 001 and EN 1992-4 and is valid in the range from normal (C20/25) to high-strength concretes (C50/60). With the development of concrete technology in recent years, special concretes (such as light weight concrete, steel fibre reinforced concrete, high-performance concrete etc.) with properties that are different from those of normal concrete are being produced and used in practice. The main objective of this research project is to investigate the applicability of the CCD-Method for design of anchorages in selected special concretes. In this project single anchors and anchor groups with different geometries in different special concretes will be investigated under tensile and shear loads. At the material level, the fracture behavior of the investigated concretes will be determined in order to investigate a possible difference in the load-bearing behavior.

Concrete breakout cone for steel fibre concrete after tensile test

Adhesive anchors on concrete surfaces

P. Schmieder, J. Hofmann

Today almost all materials in use can be connected by using adhesives. Since the bonding process is virtually heat-free, the structure of the joining materials is not changed. As a result, even very large joining parts (adherents) can be bonded and virtually any desired material composites can be produced which were till date not so feasible. Adhesive anchors on component surfaces, in particular concrete, are one of the most recent developments in the field of fastening technology. The tensile adhesion is influenced by several parameters such as the form of the surface, releasing agent, compaction, curing or contamination of concrete. The reasons for the restricted application in safety-relevant areas of construction are due to the uncertainty in the assessment of aging, long-term behavior and durability, which are required in the construction industry, particularly with regard to the admission criteria and stability over very long periods. The quality of adhesive bonding depends on the adhesion of the adhesive to the bonding surface, the adhesion strength of the material, the design of the adhesive bond and the type and direction of the stress.

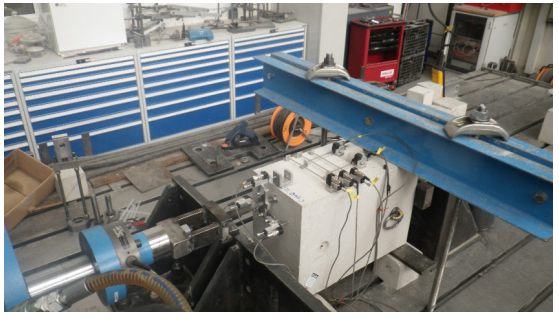


Tension load test with steel plate S 235 (diameter 80 mm) and epoxy mortar

Investigations on the bond behavior of post-installed reinforcing bars using beam end test specimen

J. Rex, A. Sharma, J. Hofmann

Adhesive mortar systems for post-installed rebars provide a significantly higher pull-out resistance, compared to cast-in reinforcing bars. In most applications of these systems the concrete cover is relatively small and thus, the bond strength of post-installed rebar systems is limited by the splitting resistance of the concrete cover. Nevertheless, most qualification tests for these systems are conducted using pull-out specimen, in which a splitting failure is excluded. Therefore, a modified beam-end test specimen for the use with post-installed reinforcing bars was developed at IWB within the scope of a research project. For a better understanding of the bond-splitting behavior of post-installed rebars several influencing parameters are being studied experimentally.

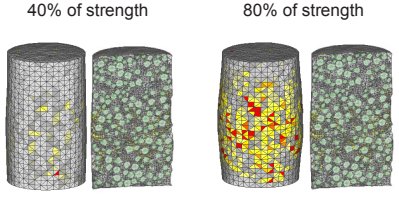


Test setup for beam end test on post-installed rebars

Interaction between damage and time-dependent deformation of mortar in concrete: 3D FE study at meso-scale

J. Ožbolt, S. Gambarelli

Creep of concrete can partly be attributed to the time-dependent deformation of cement paste and partly to the interaction between the load-induced damage of mortar (hardened cement paste) and its non-elastic deformations. The heterogeneity of concrete and related interaction between load-induced damage and non-elastic deformation of mortar can have significant influence on the long-term response of concrete. Some aspects of the problem are investigated numerically through a 3D finite element analysis of a concrete cylinder at meso-scale. The concrete is treated as a bi-phase composite material, consisting of coarse aggregate and mortar matrix. The constitutive law for mortar is based on the microplane theory, while the aggregate is assumed to be linear elastic. For different levels of applied uniaxial compressive load the influence of basic creep and shrinkage of mortar and variation of environmental temperature is investigated. It is shown that with higher loading level the increase of deformation of concrete in time becomes progressive. This is related to the interaction between the load-induced damage of mortar and its non-elastic deformations, especially shrinkage and thermal strains. These contributions to the creep of concrete can be higher than the contribution related to the creep of hardened cement paste.



Damage of concrete for different load levels: Load shrinkage of mortar (after 27 years)

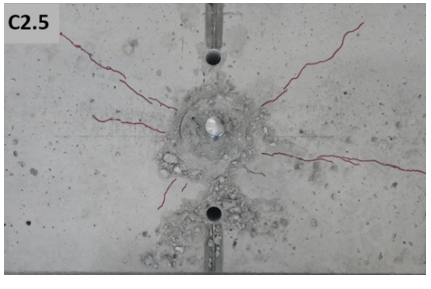
Investigation of ultimate tension capacity for special anchor set under seismic condition

S. Karatay-Akkaya, M.Potthoff

The anchor system was investigated as per category C2.5, ETAG 001 Annex E in order to be used as foundation anchoring under tension load in seismic areas.

This system consists of a steel tube and a single rod with anchor plate, attached to the bottom part of the rod. The steel tube was cast in the concrete, while the rod along with the anchor plate was installed later with the help of pouring grout.

The project aims to evaluate the ultimate tension capacity of the system under varying crack width subjected to repeated crack opening and closing. While performing the test and maintaining a specified tension loading, the crack was opened and closed horizontally in a cyclic method upto the number of cycles mentioned in ETAG. After that, the load was increased in the rod and the same procedure of crack opening and closing was carried out. The crack width was increased after every defined number of cycles. Based on the test results, the system can be used in seismic areas.

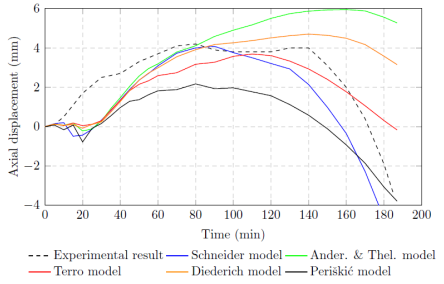


Failure pattern of anchor set

Suitability of various load induced thermal strains (LITS) formulations for 3D FE analysis using coupled thermo-mechanical model

H. Lakhani, J. Ožbolt, B. Boldbataar

At elevated temperature the total strain in concrete consists of mechanical-strains, free-thermal-strains and Load-Induced-Thermal-Strains (LITS). The most complex and relatively-less understood strain component is the LITS which basically accounts for strains due to chemical changes, moisture loss, transient creep, shrinkage etc. It is important to emphasis the fact that LITS formulations available in literature are based on limited experimental studies where concrete is under a uniaxial state of stress. Hence, their suitability for 3D FE analysis using coupled thermo-mechanical-models was studied. The constitutive law for concrete is based on the microplane theory, and the microplane model parameters are temperature dependent. The predicted behaviour of RC column under fire using different formulations is shown in figure below. It was observed that the Schneider's model gave the most reasonable results as compared to other models considered. Similar observation was obtained for all cases studied with different load-levels and aggregate types.



Predicted behavior of RC column under fire

Testing and Research Competence

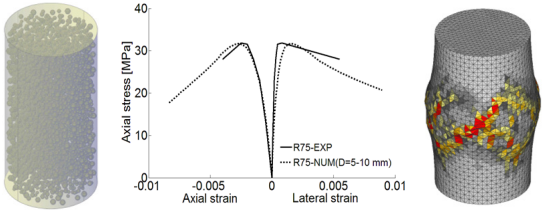
Testing Laboratory

400 kN Servohydraulic cylinder including measuring station

The state-of-the-art laboratory of IWB is equipped with several servo hydraulic cylinders and actuators for load-, displacement and deformation- control tests under static or cyclic loading. Research and approval tests on anchorages and components under uniaxial or biaxial loading in tension, shear, interaction, crack opening with different loading combinations and protocols are performed on daily basis. In order to cater for increased number of requests for C-category (seismic) testing according ETAG001, Annex E, recently a 400 kN servo hydraulic cylinder including an autonomic measuring station has been purchased to which 16 channels can be connected and measurements at a sampling rate of up to 4 kHz can be made.

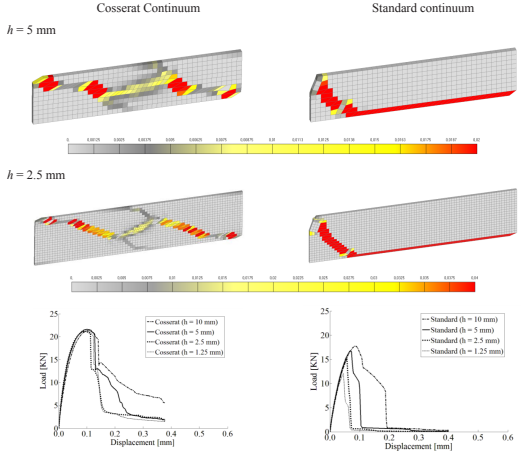
Numerical Simulations

In order to support experimental tests and better understand different problems related to the complex behaviour of concrete and reinforced concrete structures, in the last two decades at the Institute of Construction Materials (IWB) a 3D Finite Element (FE) code MASA was developed. The code is aimed to be used for the non-linear analysis of concrete and reinforced concrete structures, although different kind of materials can also be simulated, e.g. metals, polymers, FRP. The code is based on the finite element method and only standard 3D solid elements can be used. Fracture and damage phenomena are modelled in the framework of continuum mechanics accounting for the basic principles of irreversible thermodynamics. As a main constitutive law the microplane model for concrete and metallic kind of materials (e.g. steel) is used. Recently, the microplane model is formulated in the framework of micro polar Cosserat Continuum and implemented into the FE code.



Modelling of concrete at the meso-scale, uniaxial compression

Moreover, standard plasticity and damage based models are available as well. The FE code is able to simulate different kind of mechanical, non-mechanical and coupled problems such as: 1) Non-linear static and sensitive multi-body dynamics, based on the rate sensitive microplane model for concrete and steel; (2) Simulation of time dependent phenomena for concrete: creep, shrinkage and hydration of cement paste; (3) Simulation of transport processes in concrete (transport of heat, water, oxygen, chlorides); (4) Simulation of concrete and reinforced concrete structures exposed to elevated temperature, based on the single phase phenomenological Hygro-Thermo-Mechanical model; (5) Simulation of chloride induced corrosion of steel reinforcement in concrete, based on the coupled Chemo-Hygro-Thermo-Mechanical model. The processes before and after depassivation of reinforcement can be simulated, including transport of rust through cracks and pores of concrete.



Mesh sensitivity study for simple shear test: Cosserat continuum vs. standard continuum: failure modes and load-displacement responses for different element sizes h

Courses offered

Master Studies

- Grundlagen der Befestigungstechnik (Hofmann)
- Praktische Befestigungstechnik (Hofmann)
- Verstärken von Stahlbetonbauwerken in Erdbebengebieten (Hofmann, Sharma)
- Behavior and modeling of engineering materials - Concrete (Ozbolt), part of COMMAS*
- Behavior and design of structures against natural and man-made hazards (Sharma, Bosnjak)
- Modeling of connections between steel and concrete (Sharma)
- Inelastic analysis of reinforced concrete structures (Sharma)
- Building Materials (Hofmann)
- Engineering Materials I (Hofmann), part of COMMAS*
- Befestigungstechnik 1 - Theorie (Fuchs)**
- Befestigungstechnik 2 - Seminar (Fuchs)**

Bachelor Studies

- Schutz, Instandsetzung und Ertüchtigung von Bauwerken (Hofmann)

PhD-Theses (2018)

- Jebara, K.: Pryout capacity and bearing behavior of stocky headed stud anchorages
- Sola, E.: Experimental and numerical study of chloride in reinforced concrete
- Stipetic, M.: Zum Tragverhalten von Verbunddübeln in ungerissenem und gerissenem Mauerwerk unter Berücksichtigung der Steingeometrie
- Ruta, D.: Numerical and experimental study of concrete structures exposed to impact and fire

*) Commas: Computational Mechanics of Materials and Structures
**) Lecture at KIT Karlsruhe, Department of Civil Engineering

Master Theses (2017/18)

- Häbe, Sebastian: Befestigungen in Stahlfaserbeton unter Querbelastung
- Boldbaatar, Batsuuri: Beaviour of reinforced concrete columns during fire
- Savchenko, I.: Ankerschienen unter Querlast mit der Versagensart „Pry-out“
- Shum, P. J.-N.: Kleben auf Beton

Bachelor Theses (2017/18)

- Bölz, A.: Kleben in der Befestigungstechnik - Konzeption eines Demonstrators
- Grauf, Kevin: Einfluss der thermischen Beanspruchung auf das Verhalten von Normal- und Faserbeton

Selected Publications (2017-18)

- Abdelatif, A.O.; Ozbolt, J.; Gambarelli, S.: 3D finite element modelling of corrosion of lap splice joints in concrete: In: Construction and Building Materials 169 (2018), pp. 124-131
- Bosnjak, J.; Sharma, A.; Öttl, C.: Modified beam-end-test setup to study the bond behavior of reinforcement in concrete after fire. In: Materials and Structures 51 (2018), Nr. 1

Teaching activities

- Eligehausen, R.; Asmus, J.; Sharma, A.: Kopfbolzenbefestigungen mit Rückhängebewehrung unter Zug- oder Querlasten senkrecht zum Rand:. In: Der Prüfingenieur (2018), Nr. 52, S. 54-67
- Kuhlmann, U.; Hofmann, J.; Ruopp, J.: Anschlüsse zwischen Stahl und Beton. In: Stahlbau Kalender 2018. Berlin: Ernst & Sohn, 2018, S. 743-804
- Lakhani, H.; Sharma, A.; Hofmann, J.: A coupled thermo-mechanical inelastic analysis approach for reinforced concrete flexural members during fire. In: Structural Concrete, online first
- Ozbolt, J.; Gambarelli, S.: Interaction between damage and time-dependent deformation of mortar in concrete: 3D FE parametric study at meso-scale. In: Meschke, G.; Pichler, B.; Rots, J.G. (Eds.): Computational Modelling of Concrete Structures. London: Taylor & Francis, 2018, pp. 229-236
- Ozbolt, J.; Sola, E.; Balabanic, G.,: Determination of critical anodic and cathodic areas in corrosion processes of steel reinforcement in concrete. In: Meschke, G.; Pichler, B.; Rots, J.G. (Eds.): Computational Modelling of Concrete Structures. London: Taylor & Francis, 2018, pp. 387-394
- Tian, K.; Ozbolt, J.; Sharma, A.; Hofmann, J.: Experimental study on concrete edge failure of single headed stud anchors after fire exposure. In: Fire Safety Journal 96 (2018), pp. 176-188

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