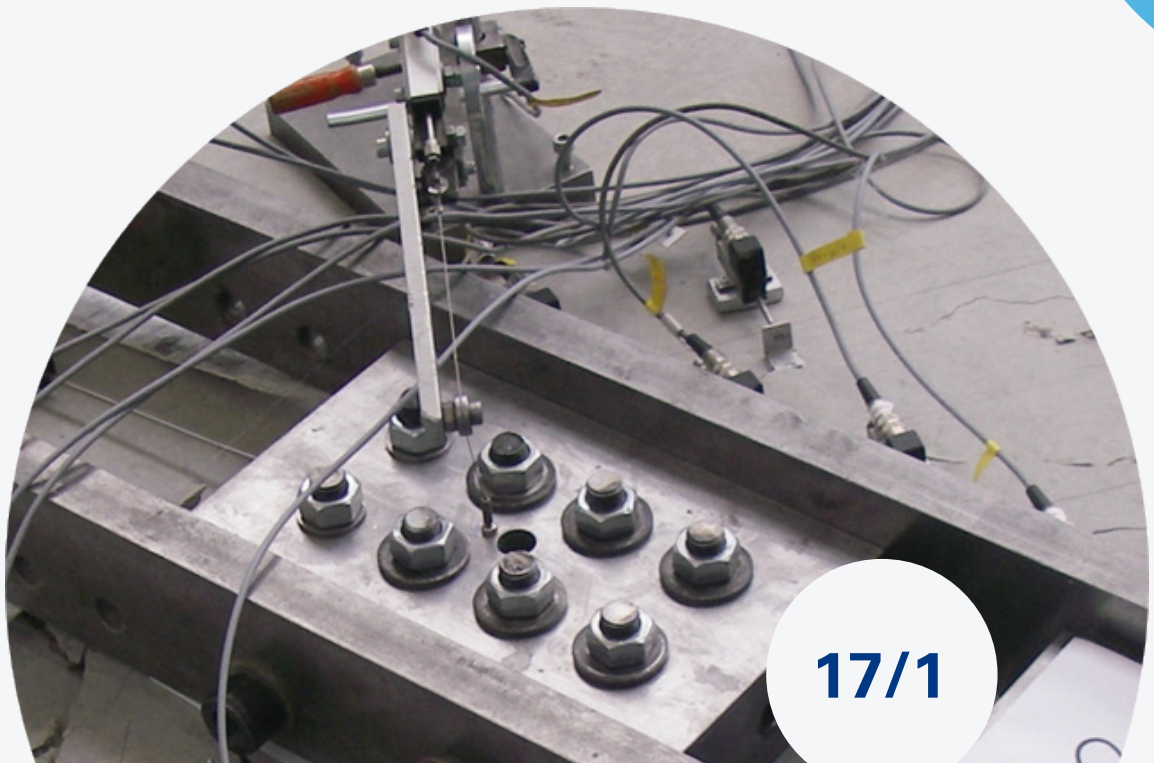
University of Stuttgart
Institute of Construction Materials

IWB

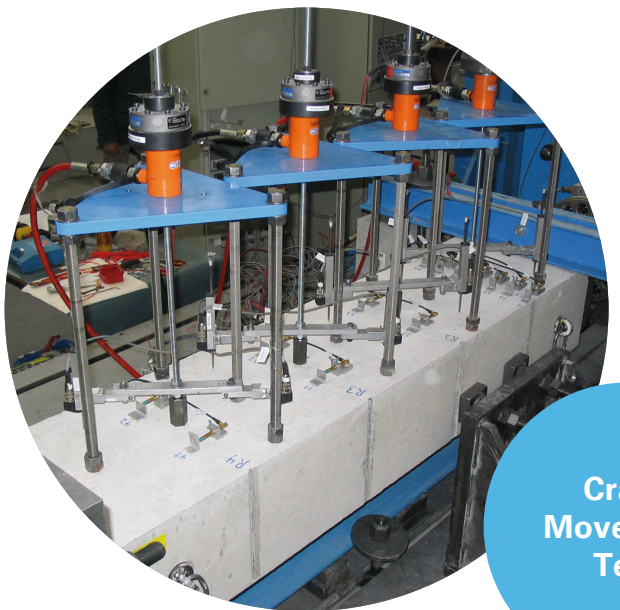
Newsletter 17/1

„Fastening Technology and Strengthening“



17/1

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



Crack Movement Test

Department of fastening and strengthening methods at the IWB, University of Stuttgart is among the leading research institutes worldwide. Majority of the research work performed at this institute has made its way into the international codes and standards. Over the years, the institute has spread its influence beyond the fields of fastening technology into the various fields of reinforced concrete as well as strengthening methods.

The institute is known to work hand-in-hand with both the industry and research organizations. The institute boasts on its capabilities to perform high quality experimental research as well as sophisticated computational modeling.

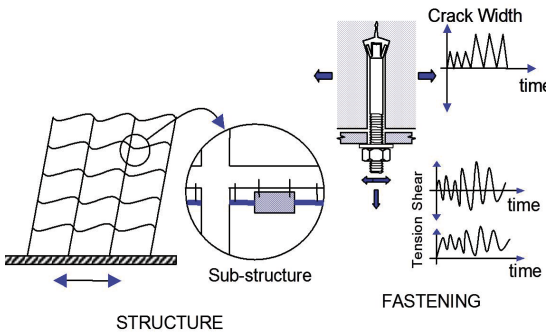
This newsletter is an initiative to keep the scientific community informed and updated about the current research projects at IWB, its research competence, experimental and numerical capabilities, teaching activities, recently completed PhD theses, Master and Bachelor theses and recent publications.

This newsletter is also a way to thank all the supporting organizations, companies and individuals for their generous support over the years and we look forward to their continuous support and cooperation in the coming years.

Research Competence

Fastening Technology

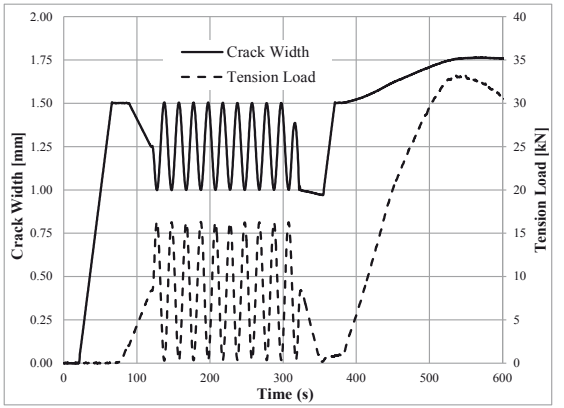
Research in Fastening Technology encompasses the study of the behavior of post-installed anchors and cast- in situ elements in concrete and masonry under short-term, shock, seismic and fatigue loading, the durability of fastenings, their interaction with the structure serving as anchor ground, special applications such as the response of anchors to fire, the evaluation of analytical models for design and the development of test methods for fastening systems.



Interaction between structure and fastening under seismic loads

The overall objective of these activities is the translation of research findings into practice, made possible by the active participation of IWB-staff in national and international code organizations such as ACI, CEN, EOTA, fib, publications in scientific journals and contribution of papers to international conferences.

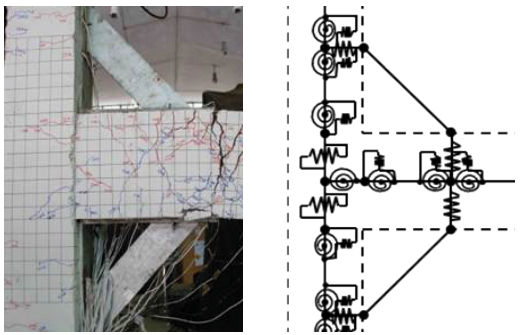
The professional work of the IWB opens the door to new fields of application for fastening systems and ensures their safe and economic use.



Out-of-phase load and crack cycling test cn anchors

Reinforced Concrete Construction

Research in reinforced concrete construction focusses on structural performance against accidental hazards such as seismic, fire and impact loads; bond between reinforcement and concrete under normal and accidental loads; strengthening of structures; application-specific design of cast-in situ and post-installed reinforcement; non-linear behavior of reinforced concrete elements.



Spring based models for nonlinear structural analysis

The experimental work is augmented by the detailed computational modeling and numerical research to investigate the internal structural mechanisms in detail and work out practical models that often find their way in structural analysis programs or international codes and standards.

Based on the experimental and numerical research, spring based models are developed to simulate the inelastic behavior of the RC structures as well as strengthening components realistically. The models are implemented in commercial software and can be used for nonlinear analysis of real-life structures.

Experiments on structural components under seismic loading

Current Research Projects

Fatigue behavior of fasteners in the case of concrete failure

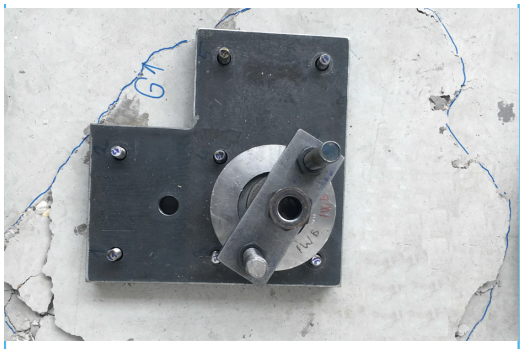
M. Toth, J. Hofmann

Guide rails of elevators, cranes or machinery with rotating parts can induce fatigue relevant loads on fasteners. When fasteners are subjected to such harmonically or periodically repeated loads, their fatigue resistance must be verified according to EN 1992-4. The EN 1992-4 covers the fatigue verifications of post-installed and cast-in fasteners under pulsating tension and pulsating and alternating shear loads up to $2*10^6$ load cycles. Since there are several applications, in which the expected number of load cycles is in the range of 10^7 to 10^9, and since this targeted cycling range is beyond the experimentally possible range, the development of a reliable numerical method is necessary that can realistically predict the fatigue life of fasteners even in the targeted high-cycle fatigue range. Furthermore, in the case of alternating cyclic loading, the anchor plate can transfer compression into the concrete, thus generating compression forces in the concrete close to the surface. Since this loading case was not investigated yet, alternating tension-compression tests were carried out in order to extend the scope of EN1992-4.

Development of a new design concept for anchor groups of arbitrary configuration

B. Bokor, A. Sharma, J. Hofmann

The current design provisions for anchor groups (EN 1992-4, ETAG 001) are based on the CCD-Method and are limited in applicability due to several requirements such as anchor plate geometry and stiffness, anchor configurations, permitted number of anchors etc. However, in reality, practical considerations call for generalized configurations of anchors



L-shaped anchor configuration under tension loads

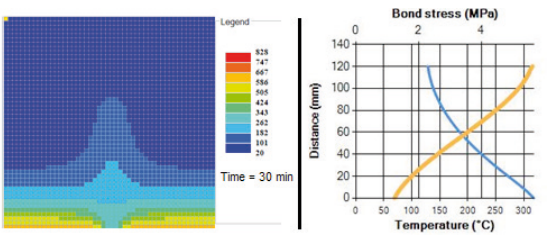
Within the scope of this research project, anchor groups of different anchor configurations combined with various anchor plate geometries are investigated. The experiments include tension and shear loading tests on anchor groups within and out of the scope of the current design provisions. The project also aims to the development of a general design concept that improves the existing design guidelines in terms of accuracy and also extends the scope of EN1992-4 for arbitrary anchor configurations and anchor plate geometry for both tension and shear loading cases

A numerical method to evaluate the strength of bonded anchors during fire

H. Lakhani, J. Hofmann

The load carrying capacity of bonded anchors is known to be strongly dependent on temperature and it reduces rapidly with rising temperature. At present EOTA TR 020 (2004) can be used for evaluating only steel failure under fire for bonded anchors. However, due to the fact that pull out failure of the anchor might be decisive, it is recommended to evaluate the bonded anchors by performing fire tests. Evaluation by fire tests is always very demanding, especially financially. It also has the limitation that the anchor can be qualified only for a particular fire scenario and its fire rating can be significantly different under different fire scenarios.

The project aims at developing a numerical model for computing the strength of bonded anchors in concrete subjected to generalised fire loads. The modeling approach basically revolves around transient heat transfer analysis (using thermal properties as a function of temperature) and integrating the temperature dependent bond strength variation along the anchor depth to obtain the anchor capacity.

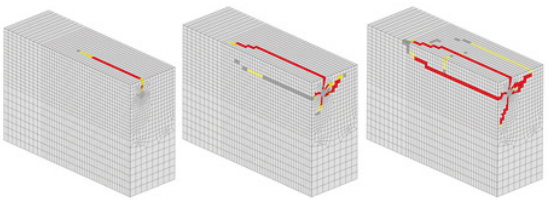


Typical variation of temperature and bond strength along anchor after 30 min of ISO fire

Corrosion of steel reinforcement in concrete

E. Sola, J. Ožbolt

Chloride-induced corrosion of steel reinforcement in concrete is one of the major causes for deterioration of reinforced concrete structures. Principally, the computation of corrosion current density requires modeling of several physical, electrochemical and mechanical processes. In the framework of the recent DFG project a coupled 3D chemo-hygro-thermo-mechanical (CHTM) model for concrete is developed and implemented into a 3D FE code. To verify and calibrate the model a series of experimental tests were conducted. The comparison between the own test results and the results from the literature showed that the model is able to realistically simulate processes before and after depassivation of steel reinforcement in concrete. The developed numerical model is important tool which can effectively be used to better understand the processes related to corrosion of steel reinforcement in concrete and help in the formulation of reliable design codes.



Corrosion induced damage: 1, 3 and 7 years after depassivation of reinforcement

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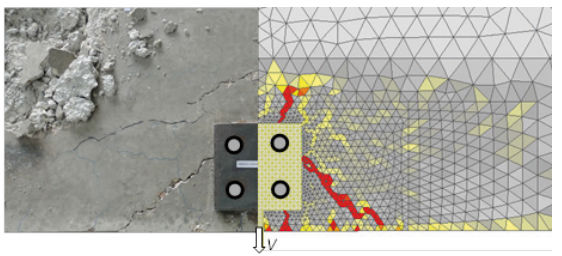
Fasteners under fire exposure

K. Tian, J. Ožbolt

To better understand the behavior of fasteners loaded in shear at elevated temperatures, fire tests on single-and group of headed stud anchors were carried out in the framework of the DFG research project „Fasteners under Fire Exposure“ for anchors close and far from edge of a concrete slab. The tests were used for the calibration and verification of the existing thermo-mechanical model that was implemented into the 3D FE code. After verification of the model a parametric study for headed studs close and far from the edge was carried out. The numerical results showed good agreement with the experimental investigations. As expected, the resistance of anchors loaded in shear is strongly reduced at elevated temperatures. The resistance of anchors in the hot state is higher than the same resistance for the cold state. The design prediction formula underestimates resistance for the hot state, however, it overestimates it for the cold state. The results of the study indicate that for the shear resistance of concrete cold state is relevant.



Concrete edge failure of a 4-anchor group exposed to 15 min of fire according to ISO 834

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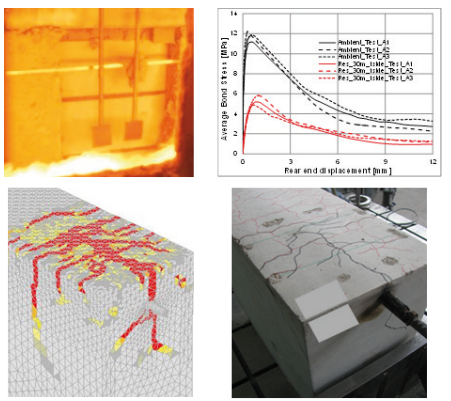
Bond under fire

A. Sharma, J. Bošnjak (MPA)

Bond behavior between reinforcement and concrete is studied using the beam-end-test specimen under realistic boundary and fire conditions. In real conditions, the reinforcing bar is protected by a relatively small cover, the heating regime is fast and non-uniform and the confinement is only partial, provided either through rectangular stirrups (beams) or bulk material (slabs). The effective bond strength obtained by tests under realistic boundary conditions may be significantly smaller than the pull-out bond strength obtained from the tests performed using confined test setup and slow heating scenarios. This is primarily attributed to the thermal damage of concrete, caused by the high thermal gradients generated during fire, which leads to concrete splitting prior to the attainment of full bond strength. Based on these tests, it is targeted to develop a model that can be used to predict the effective bond strength between reinforcement in concrete considering realistic boundary conditions and fire scenario.



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Testing Laboratory

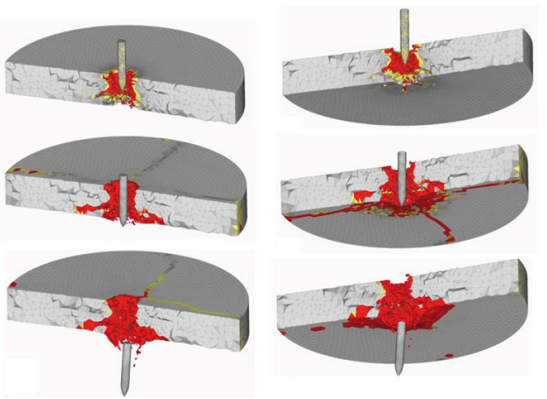
Tension load test under varying crack width

Since 1998, IWB established its own testing laboratory in Stuttgart. We are able to perform all the tests according to ETAG 001, International Standards and National regulations. Our Laboratory is accredited according to DIN EN ISO / IEC 17025 from DAKKs and IAS since 2000. The development of own testing methods with transfer to national and international testing methods is stated in the accreditations.

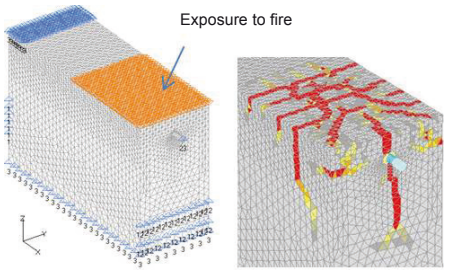
With our equipment and competent staff, we are able to perform tests in cracked, uncracked, dry and wet concrete.

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 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. Moreover, standard plasticity and damage based models are available as well. The FE cod is able to simulate different kind of mechanical, non-mechanical and coupled problems such as:

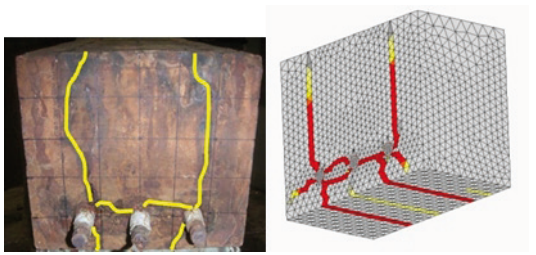


Penetration of projectile through concrete slab
(impact velocity=300 m/s)



Bond failure at elevated temperatures, FE Discretization & failure mode after 15 min of exposure

(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.



Chloride induced corrosion of reinforcement; corrosion induced damage, experiment and analysis

Teaching activities

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 (2017)

- Schmidt, T.: Tragverhalten von Ankerschienen unter Querlast in Schienenlängsrichtung

Master Theses (2017)

- Al Assadi, A.: Modelling approach for anchorages in retrofitting reinforced concrete frame with steel brace elements
- Ewersmeyer, K.: Zur Mauerwerksfestigkeit für die nichtlineare Finite-Element-Methode
- Kansy, C.: Untersuchung der Einflüsse von Normal- und Querkraft auf das Tragverhalten von Mauerwerk mithilfe der nichtlinearen Finite Elemente Methode
- Kraft, S.: Zur Berechnung der Mauerwerksfestigkeit im ebenen Spannungszustand
- Hahn, P: Das Verhalten von Mauerwerk unter dem Einfluss verschiedener Lagerfugenwinkel

Bachelor Theses (2017)

- Eckstein, M.Y.: Einfluss der Dauerbelastung auf die Kurzzeittragfähigkeit von Verbunddübeln
- Wiedemann, I.: Vergleich von Oberflächenschutzsystemen hinsichtlich Korrosionsschutz anhand ausgewählter Fallbeispiele

Selected Journal Publications (2017)

- Asmus, J.; Eligehausen, R.; Sharma, A.: Steigerung der Tragfähigkeit von Kopfbolzengruppen – Verbesserte Bemessungsmodelle gegenüber EC 2. In: Betonwerk und Fertigteiltechnik (2017), Nr.2, S. 89-90
- Chellapandian M, Prakash SS, Sharma A, “Strength and ductility of innovative hybrid NSM reinforced and FRP confined short RC columns under axial compression”, Composite Structures 176 (2017) 205–216.
- Fuchs, W.; Hofmann, J.: Shallow embedded anchors - load-carrying-capacity of mechnical anchors under tension. In: Concrete International (2017), Nr. 2, S. 45-53
- Lin, H.; Zhao, Y.; Ozbolt, J.; Reinhardt, H.-W.: The bond behavior between concrete and corroded steel bar under repeated loading. In: Engineering Structures 140 (2017), S. 390-405
- Mahrenholtz, C.; Sharma, A.: Testing of anchors and reinforcing bars in concrete under cyclic crack movements. In: Journal of testing and evaluation (2017), Nr. 4
- Sharma A, Eligehausen R, Asmus J., “A new model for concrete edge failure of multiple row anchorages with supplementary reinforcement - Reinforcement failure”, Structural Concrete, (2017); 0: 1–9. https://doi.org/10.1002/suco.201700002
- Sharma, A.; Eligehausen, R.; Asmus, J.: Experimental investigation of concrete edge failure of multiple-row anchorages with supplementary reinforcement. In: Structural Concrete 18 (2017); Nr. 1, pp. 153-163

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

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