Christian U. Grosse

Advances in Construction Materials 2007

With 578 Figures and 80 Tables
This book addresses one of the most important material categories: Materials used for constructions. A large percentage of the gross national product of most countries goes into infrastructure and buildings. This statement is true not only for the present but for most other periods in history, and for most cultures. This explains why understanding the behavior of construction materials has always been the object of intense investigations. The construction industry consumes extreme volumes of material, and the growing demand for quality and safety require continuous improvement of materials and material compositions. A deep understanding of material behavior is essential to enable efficient construction: light-weight or heavily burdened structures ask for the development of innovative composites or new material compositions. Rapid economic growth and a dense and growing population require sensitive and sustainable use of resources. Finally efficient use of resources means extending the usage of existing structures, so non-destructive testing methods are needed to assess the safety and utility of these structures.

Civil Engineers and Material Scientists from all over the world are openly discussing ideas for new materials, and for structural health monitoring. Over the last decade many innovations have come to fruition, primarily in the field of composites but also for improving the design of existing material. This is especially true for concrete, perhaps the most used material in the world – broadening its range of applications and improving performance. Some of these developments include high-strength and high-performance concrete (HPC), self-compacting concrete (SCC), shotcrete, textile or fiber reinforced concrete (FRC), and chemical and mechanical additives. Performance can be further optimized by combining these improvements. Enhancement of material behavior and physical properties were also made for most other construction materials (e.g. wood, masonry, steel, polymers) as well.

This book contains descriptions of some of these developments giving a thorough overview about the state-of-the-art in construction material science. The book is subdivided in nine chapters addressing most of these aspects. Some of the leading experts in their particular research fields present their results – experts that are all more or less closely related to one impressive person: Prof. Dr.-Ing. Hans W. Reinhardt. The research in the field of construction materials was (and is) always influenced by dominant researchers, so many contributions in this book are dedicated to Reinhardt. Therefore, it is just consequent to start the book with a review about his scientific achievements up to his recent retirement.

The papers here presented were originally submitted to the conference on Advances in Construction Materials (ACM2007) which is held in July 2007 in Stuttgart which is also dedicated to Reinhardt’s work. This book addresses perhaps the
key element of Reinhardt’s contributions: Materials used for constructions as well as improvement and testing of structures.

The editor is grateful for the help of two hard workers who made this compilation possible. Mrs. Simone Stumpp has to be thanked first. She is always friendly, solid and maintained a high commitment to work. Her help was essential to all parts of the book production and conference preparation. Mrs. Anne Lehan was a very enthusiastic and dependable worker during the preparation and formatting of the manuscripts. This book would certainly not have been possible without both.

Finally, the generous contributions of the following companies have to be mentioned:

SAFA Saarfilterasche-Vertriebs-GmbH & Co. KG, Baden-Baden
Bundesverband Mineralische Rohstoffe e.V., Köln
Verein Deutscher Zementwerke e.V., Düsseldorf
Fa. BauMineral GmbH, Herten
Fa. MC-Bauchemie Müller GmbH & Co. KG, Bottrop
Bilfinger Berger AG, Mannheim

Stuttgart, July 2007, Christian U. Grosse (Editor)
# Table of Contents

Brief Review of the Scientific Work of Prof. Dr.-Ing. Hans W. Reinhardt .... 1  
*Christian U. Grosse*

Towards a better visibility of outstanding research ................................. 15  
*Michel Brusin, Matthieu Duvivier*

---

## Part I Aspects of Structural Engineering

Actual tendencies in structural fastening technology .............................. 23  
*Rolf Eligehausen, Werner Fuchs*

Constitutive Laws for Concrete and their Application  
with Numerical Methods ........................................................................... 31  
*Ulrich Häussler-Combe, Patrick Pröchtel*

Innovations in concrete technology: Interaction between research,  
codes and applications ............................................................................... 39  
*Dick A. Hordijk*

Ultra-high performance concrete for the roof of a research  
hot water storage ...................................................................................... 49  
*Achim Lichtenfels*

Numerical modelling of cam-pocket coupling systems for concrete lining.... 57  
*Peter-Michael Mayer, Ana Libreros-Bertini, Hans M. Hilber*

Uncertainty models for safety assessment of textile reinforced  
concrete structures .................................................................................... 67  
*Bernd Möller, Wolfgang Graf, Andreas Hoffmann, Jan-Uwe Sickert*

Structural design of a large foundation slab close to reality, stiffness  
oriented design method CTD ................................................................... 75  
*Piotr Noakowski, Holger Leszinski*
Steel castings in architecture and engineering ................................................. 83  
Jörg Schlaich, Hans Schober

Load-bearing and deformation behaviour of concrete beams reinforced in combination of both steel bars and bars made of glass fibre reinforced plastic (GFRP) ................................................................. 109 
Jürgen Schnell, Matthias Pahn

Part II Fiber Composites

Mechanical and Fracture Mechanical Properties of Fine Grained Concrete for TRC Structures ................................................................. 119 
Tanja Brockmann

Enriched finite element representation of 2D multi-cracking and debonding in textile reinforced concrete...................................................... 131 
Rostislav Chudoba, Frank Peiffer, Przemzlaw Zakrzewski, Jacub Jerabek, Josef Hegger

Fracture properties of high-strength hybrid fiber-reinforced concrete .............. 139 
Luca Cominoli, Alberto Meda, Giovanni A. Plizzari

Textile Reinforced Concrete – A new Composite Material .............................. 147 
Josef Hegger, Norbert Will, Karolin Rüberg

Viscoelastic behavior of a strain hardening Ultra High Performance Fiber Reinforced Concrete ................................................................. 157 
Aicha Kamen, Emmanuel Denarié, Eugen Brühwiler

Ductility and Fatigue Behaviour of Polymer-Modified and Fibre-Reinforced High-Performance Concrete ...................................................... 165 
Ludger Lohaus, Steffen Anders

Bond Cracking and Tension Stiffening Properties of a Deformed Bar Embedded in HPF RCC ................................................................. 173 
Hirozo Mihashi, Koji Otsuka, Hiroshi Akita, Toshifumi Kikuchi

Tensile strain-hardening FRC composites: Historical evolution since the 1960 ................................................................. 181 
Antoine E. Naaman

UHPFRC protection layer on the crash barrier walls of a bridge .................... 203 
Cornelius Oesterlee, Emmanuel Denarié, Eugen Brühwiler
Scale effect and combined loading of thin UHPFRC members.......................... 211
Karl-Heinz Reineck, Stefan Greiner

Hybrid fibre concrete: is there a synergetic effect?........................................ 219
Lucie Vandewalle

Ultra high performance fibre reinforced cement composite
under dynamic loading.................................................................................. 229
Silvia Weber, Andreas Rümmelin

An Experimental Study on Bending Behavior of Cementitious
Composites Reinforced in Combination with Carbon Textile
and Short-Cut PVA Fiber.............................................................................. 237
Shilang Xu, Qinghua Li

Part III Repair Materials and Strengthening Methods

Performance of concrete patch repair systems.............................................. 255
Hans-Dieter Beushausen, Mark Gavin Alexander

Repair of cracked reinforced concrete by injection after
accidental loading ....................................................................................... 263
Maximilian Fuchs, Manfred Keuser

Seismic strengthening of piers with partial use of high ductility cement....... 269
Kenji Kosa, Kazuya Wakita, Hiroki Goda, Atsuhisa Ogawa

Sprayed GFRP shear-strengthened reinforced concrete Beams
under Impact Loading ................................................................................ 279
Sayed M. Soleimani, Nemkumar Banthia, Sidney Mindess

Part IV High Temperature and Fire Resistance

High Strength Fiber Composites for fabricating fire-resistant wood
with improved mechanical properties ......................................................... 289
James W. Giancaspro, Perumalsamy N. Balaguru, Ken Chong

Mechanical properties of SFRC at high temperatures.................................. 299
Matteo Colombo, Marco di Prisco

Modifications of material properties due to elevated temperatures .......... 307
Éva Lublóy, György L. Balázs
## Part V Corrosion and Durability

Influence of cyclic loading on the degradation of mechanical concrete properties ........................................................................................................ 317
Rolf Breitenbücher, Hursit Ibuk, Hussein Alawieh

A material model for creep and fatigue applied to asphalt ........................................ 325
Elisabeth Herz, Michael Vormwald

Simulation of the cyclic loading and damage behavior of gypsum composites ........................................................................................................ 335
Wolfgang Lutz, Feng Guo, Siegfried Schmauder, Rüdiger Finn, Siemon Aicher

Superabsorbent Polymers – An Additive to Increase the Freeze-Thaw Resistance of High Strength Concrete ............................................................. 351
Sven Mönnig, Pietro Lura

Corrosion products pressure needed to crack the concrete cover .................... 359
Alejandro Munoz, Carmen Andrade, Andrés Torres

Failure mechanisms in fatigue of high strength steel wires for cable-constructions ........................................................................................................ 371
Ulf Nürnberger

Durability aspects of AR-glass-reinforcement in textile reinforced concrete, Part 1: Material behaviour .......................................................... 381
Heidi Cuypers, Jeanette Orlowsky, Michael Raupach, Till Büttner

Durability aspects of AR-glass-reinforcement in textile reinforced concrete, Part 2: Modelling and exposure to outdoor weathering ................... 389
Heidi Cuypers, Jeanette Orlowsky, Michael Raupach, Till Büttner, Jan Wastiels

Stress corrosion cracking mechanism of prestressing steels in bicarbonate solutions .................................................................................. 397
Javier Sanchez, José Fullea, Carmen Andrade

Moisture Transport in Concrete – Field Tests and Hygrothermal Simulations ........................................................................ 405
Andreas Holm, Martin Krus, Hartwig M. Künzel, Klaus Sedlbauer

Impact of Freeze-Thaw Degradation on FRP-Concrete Interface Fracture ............................................................................................. 419
Kolluru V. Subramaniam, Michel Ghosn, Mohamad Ali-Ahmad

Effective chloride barrier for reinforced concrete structures in order to extend the service-life ............................................................. 427
Folker H. Wittmann
Part VI Properties, Modeling and Testing of Fresh Concrete

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setting and hardening of cement based materials: which differences</td>
<td>441</td>
</tr>
<tr>
<td>between mortars and concretes?</td>
<td></td>
</tr>
<tr>
<td><em>Laurent Arnaud, Michaël Dierkens</em></td>
<td></td>
</tr>
<tr>
<td>Mechanical properties of cement mortars with superabsorbent polymers</td>
<td>451</td>
</tr>
<tr>
<td><em>Luís P. Esteves, Paulo Cachim, Victor M. Ferreira</em></td>
<td></td>
</tr>
<tr>
<td>Formwork Pressure of Concretes with high Workability</td>
<td>463</td>
</tr>
<tr>
<td><em>Tilo Proske, Carl-Alexander Graubner</em></td>
<td></td>
</tr>
<tr>
<td>Modern statistical methods for accessing the hardening process</td>
<td>471</td>
</tr>
<tr>
<td>of concrete</td>
<td></td>
</tr>
<tr>
<td><em>Eddy A.B. Koenders, H. van der Ham, Klaas van Breugel</em></td>
<td></td>
</tr>
<tr>
<td>Virtual concrete laboratory – Continuous numerical modelling</td>
<td>479</td>
</tr>
<tr>
<td>of concrete from fresh to the hardened state</td>
<td></td>
</tr>
<tr>
<td><em>Viktor Mechtcherine, Sergiy Shyshko</em></td>
<td></td>
</tr>
<tr>
<td>Detection of early-age cracking due to restrained autogenous shrinkage</td>
<td>489</td>
</tr>
<tr>
<td><em>Patrick Fontana, Stephan Pirskawetz, Frank Weise, Birgit Meng</em></td>
<td></td>
</tr>
<tr>
<td>Ultrasonic and calorimetric measurements on fresh concrete</td>
<td>497</td>
</tr>
<tr>
<td>with blast-furnace slag</td>
<td></td>
</tr>
<tr>
<td><em>Nicolas Robeyst, Elke Gruyaert, Nele De Belie</em></td>
<td></td>
</tr>
<tr>
<td>Fresh concrete pressure in diaphragm wall panels and</td>
<td>505</td>
</tr>
<tr>
<td>resulting deformations</td>
<td></td>
</tr>
<tr>
<td><em>Hermann Schad, Pieter A. Vermeer, Annette Lächler</em></td>
<td></td>
</tr>
<tr>
<td>SCC and UHPC – Effect of Mixing Technology</td>
<td>513</td>
</tr>
<tr>
<td>on Fresh Concrete Properties</td>
<td></td>
</tr>
<tr>
<td><em>Peter Schießl, Oliver Mazanec, Dirk Lowke</em></td>
<td></td>
</tr>
<tr>
<td>Analytical model for hydration of blended cement</td>
<td>523</td>
</tr>
<tr>
<td><em>Geert De Schutter</em></td>
<td></td>
</tr>
<tr>
<td>Nucleation and growth of C-S-H phases on mineral admixtures</td>
<td>531</td>
</tr>
<tr>
<td><em>Jochen Stark, Bernd Möser, Frank Bellmann</em></td>
<td></td>
</tr>
<tr>
<td>Improving the slipform process via material manipulation</td>
<td>539</td>
</tr>
<tr>
<td><em>Nathan Tregger, Thomas Voigt, Surendra P. Shah</em></td>
<td></td>
</tr>
</tbody>
</table>
Part VII Non-destructive Testing Methods and Applications

Sensing methods in civil engineering for an efficient construction management ........................................................................................................... 549
Christian U. Grosse, Christoph Gehlen, Steven D. Glaser

Fast Non-Destructive Localisation of Prestressing Steel Fractures in Post-Tensioned Concrete Bridges ........................................................................... 563
Bernd Hillemeier, Andrei Walther

New Possibilities for Ultrasonic Imaging of Concrete Elements ...................... 575
Martin Krause, Boris Gräfe, Frank Mielentz, Boris Milmann, Doreen Streicher

Quantitative Non-Destructive Testing: The integration of non-destructive testing and probabilistic fracture mechanics .................................................... 583
Jochen H. Kurz, Dragos Cioclov, Gerd Dobmann

Advances in the in-situ assessment of construction materials ......................... 591
Adrian E. Long, P.A. Muhammed Basheer, Lulu Basheer

Detection and analysis of microcracks in high-performance cementitious materials ........................................................................................................... 607
Pietro Lura, Jason Weiss, Ole Mejlhede Jensen

Acoustic Emission Techniques for Rebar Corrosion in Reinforced Concrete ....................................................................................................................... 615
Masayasu Ohtsu, Yuichi Tomoda

Online-Monitoring of Thermal Restraint Stresses for a Railways Trough Structure due to the Coupling of Trough and Underwater Concrete Slab ...... 623
Ferdinand S. Rostásy

Radar and Fusion for Concrete Elements ........................................................ 631
Christiane Maierhofer, Gerhard Zacher, Christoph Kohl, Jens Wöstmann

Inspection of Prestressed Concrete Members using the Magnetic Leakage Flux Measurement Method – Estimation of Detection Limit ....................... 639
Gottfried Sawade, Hans-Joachim Krause
Part VIII Environment and Sustainability

Abatement of Acid Mine Drainage Using Industrial Waste Products
Amde M. Amde, Abebe Dinku, Omar Davies

Finely Ground Sand Fraction of Concrete Rubble as a Supplementary Cementitious Material
Detlef Heinz, Jürgen Schubert

Numerical Simulation of Air-Steam Leakage Behaviour of Reinforced Concrete Walls
Christoph Niklasch, Lothar Stempniewski

Sustainable building with concrete – a holistic approach along the Life-Cycle
Gerd Thielen, Udo Wiens, Bruno Hauer

Dangerous Substances in Building Materials – Emissions from PCB Coated Ceiling Panels – Polychlorinated Biphenyls (PCB) in Indoor Air
Gerhard Volland, Dagmar Hansen, Dieter Zöltzer

Demountable concrete buildings, structural design of floor slabs with concrete elements and aluminium foam
Georg Christian Weiss

Reduction of the Penetration of Water-Hazardous Liquids into Concrete using Silica Fume and Polymer Dispersions
Udo Wiens, Christoph Alfès

Part IX Mechanical and Thermal Properties of Materials

Tension Softening Curves Described by Algebraic Formulas and Artificial Neural Networks
Dariusz Alterman, Hiroshi Akita, Janusz Kasperkiewicz

Effects of a clay additive on the properties of no-slump concrete
Harald Budelmann, Karim Hariri, Hans-Werner Krauss, Tim Malonn

Development of thermal insulation materials with granular phase change composite
Zongjin Li, Xiangyu Li
Examination of the relation between tensile/flexural strength and compressive strength of autoclaved aerated concrete according to prEN 12602 ............................................................. 749
Christian Öttl, Hans Schellhorn

Modern perspectives on aggregate in concrete .................................................. 757
Piet Stroeven, Zhan-Qi Guo

Research developments and experimental data on dynamic concrete behaviour................................................................. 765
Jaap Weerheijm, Ilse Vegt, Klaas van Breugel

Index ............................................................................................................... 775
Brief Review of the Scientific Work of Prof. Dr.-Ing. Hans W. Reinhardt

Christian U. Grosse
Materialprüfungsanstalt Universität Stuttgart, Postfach 801140, D-70511 Stuttgart, Germany. E-mail: christian.grosse@mpa.uni-stuttgart.de

Introduction

The contributions in this book are dedicated to the person and work of Hans-Wolf Reinhardt. Consequently, this paper describes stages of his scientific work, which is related to a variety of different fields in Civil Engineering such as construction materials, fracture mechanics and non-destructive testing. He investigated an amazing variety of different materials and material compositions including concrete (SFRC, HPC, SCC), wood and aluminum. His impressive vita comprises tenures at the University of Delft, the University of Darmstadt and the University of Stuttgart. The following chapters is an overview of the many contributions to our science that Prof. Reinhardt gave. The brief descriptions are certainly neither complete nor in the only possible order. The order chosen is merely based on the sequence of events during his scientific work at different institutions. One can imagine how he was influenced by the collaborators and scientific environment. However, many of the contributions in the following chapters of this book are directly related to his work summarized in this paper. It is also necessary to mention that he is still active with several scientific projects – he will continue to contribute with new research results.

Stuttgart: May 1964 – September 1969

Reinhardt finished his University Diploma in Civil Engineering at the University of Stuttgart in 1964 and got a PhD position by Prof. Gustav Weil. From the beginning Reinhardt was closely related to the Otto-Graf-Institute in Stuttgart. Gustav
Weil was one of the assistants of Otto Graf, who was head of the Institut für Bau- 
forschung und Materialprüfung des Bauwesens (Institute of Building Materials 
and Materials Testing of Civil Engineering) from 1927 up to 1950. Friedrich 
Tölke was head of the institute between 1952 and 1969 and during his time the in-
stitute was renamed Amtliche Forschungs- und Materialprüfungsanstalt für das 
Bauwesen (FMPA-Bauwesen) (Official Research and Materials Testing Institute 
of Civil Engineering (FMPA-Civil Engineering). In honour of Prof. Otto Graf’s 
work the institute received the additional name “Otto-Graf-Institute”. Friedrich 
Tölke was than succeeded by Weil (1969 to 1972), who – like his successors – 
held the chair and lectured constructional science at the University of Stuttgart.

Since Weil was collaborating with Otto Graf for a rather long time it is not sur-
prizing that road construction using concrete was one of the research subjects at 
that time. When Reinhardt took over a position under the supervision of Weil 
there were three road construction projects at the Otto-Graf-Institute (OGI) includ-
ing the test track near Offenburg, the determination of shrinkage of embedded 
concrete plates and the examination of temperature distributions in such plates. 
The test track near Offenburg was part of the historical “HaFraBa” track that was 
in fact one of the first big highway projects in Germany connecting the Hanseatic 
cities with Frankfurt and Basel. Here, load cycle fatigue tests were conducted at 
joints and Reinhardt took over the task to file a summarizing report for the Ger-
man Federal Ministry of Transportation. Realistic model specimen were concreted 
at an open site near the institute and used to investigate the shrinkage and tempera-
ture behaviour. All OGI assistants had to take over tasks to control the instruments 
and read the data in summer, winter, day and night. Reinhardt developed a method 
to calculate the stress distribution in multi-layered plates that was later applied to 
veneer plates.

Fig. 1. IBM 1130 mainframe computer Reinhardt used for his PhD thesis [by courtesy of 
Computer Museum of the University of Stuttgart]
The PhD thesis Reinhardt compiled during these years was dealing with photoelasticity of thermal stress. He was influenced by lectures given by Prof. Kuske, who demonstrated how stress can be visualised. In these days the three-dimensional stress distribution in construction materials was not understood and therefore Reinhardt used the composite-model technique based on interface layers using non-birefringent materials. It was a challenge to find such materials able to react chemically, being transparent and having similar mechanical and thermal properties. He finally succeeded using a mix of acrylic and polyester resins resolved in styrol and methylmethacrylate. The experiments using cylindrical specimens were analyzed using state-of-the-art computers. Reinhardt was one of the first OGI assistants being trained by IBM to use the IBM 1130 mainframe computer (Fig. 1) with 16 kByte RAM and a punch card interface. More details about the experiments and results can be found in the thesis itself [Reinhardt 1969].

**Chicago: September 1969 – September 1970**

A post-doc position was granted by the Max-Kade Foundation, New York, to H.-W. Reinhardt. He decided to go to the Illinois Institute of Technology (IIT) in Chicago, to work with Prof. James W. Dally. Dally was well-known for publications using dynamic photo-elasticity and was at these days evaluating wave propagation effects. In particular he investigated the behaviour of Rayleigh waves diffracted at a crack as well as the effect of explosives used for quarry blasting. The IIT was in the possession of a Cranz-Schardin camera using spark discharges for high-speed recordings; up to 16 pictures could have been made in a few microseconds. Doing research in the field of wave propagation he needed to study the basic principles by following lectures at the IIT and reading books [Victorov 1967]. As it is not unusual at US Universities there were no technicians available to support his work and he needed to do all the experimental work on his own: milling of specimen, adjusting the camera, preparation of specimen with explosives (lead acetate), conducting the experiments and developing the photographic film. [Reinhardt/Dally 1970]

**Stuttgart: October 1970 – September 1975**

Being back in Stuttgart, Reinhardt (now as Oberassistent and Akademischer Rat) proceeded with the work on road track concrete, but the work was interrupted by the sudden death of Prof. Weil caused by a traffic accident in Spring 1972. Reinhardt was asked to substitute Weil regarding teaching until a successor was found. This was Prof. Gallus Rehm, who started to work as a director of FMPA in Fall 1973 and was entrusted among other things with a research project called “Widespan Structures” („Weitgespannte Flächentragwerke“, Sonderforschungsbereichs 64). In this
frame Reinhardt was put in charge with a subproject dealing with the evaluation of the two-dimensional behaviour of coated textiles. He was able to use a biaxial test machine that was transferred from the Department of Mechanics to the OGI [Losch 1971]. This machine enabled for controlled biaxial stress-strain conditions during the experiments. The results [Reinhardt 1976] influenced the construction praxis in Germany and for example were used during the construction of a multi-purpose hall in Mannheim (Fig. 2) designed by Carlfried Mutschler, Joachim Langner and Frei Otto (http://de.wikipedia.org/wiki/Multihalle).

In civil engineering there is a huge interest to gain knowledge about the effect of stress inside a membrane-shaped structure and therefore a measuring device needed to be developed. Reinhardt developed together with colleagues from the department of steel structures a ring-shaped device able to aspirate at a membrane and to deform the structure. A measurement of the deflection enabled for the determination of the stress status inside warp and weft.

Delft: **October 1975 – August 1986**

In 1975 Reinhardt got a chair for Structural Engineering at the Department of Design and Construction of the Technical University of Delft, The Netherlands. At this time the new Stevin Lab was inaugurated and Reinhardt became director of
the concrete section of this laboratory. He was able to support the installation of
the measurement equipment and machineries. His inaugural lecture (Fig. 3) was
entitled “Demountable buildings using concrete?” that was a controversial subject
but led to a research project funded by the “CUR commission” (a Dutch institution
to support research and development of concrete structures). Demountable struc-
tures were designed as well as flexible joints of prefabricated concrete parts and
experiments were conducted loading slabs horizontally. For practical applications
several systems for school, clinical and office buildings were designed. In May
1985 a first international symposium entitled “Demountable concrete structures –
A challenge for precast concrete” was held in Rotterdam.

Another subject he was intensively working on at TU Delft was the fracture
mechanics of concrete. Based on shear experiments conducted at these times in
Delft Reinhardt became interested in the problem of tension behaviour of concrete
that is usually investigated using split tests. This class of experiments developed
values for the tensile strength but provided no details about the stress-strain rela-
tionship. Measuring techniques dealing with axial tension in analogy to steel have
not been fully developed at this time. With adhesives recently launched he was
able to use plates attached to cylindrical specimen to load until failure, but a con-
trolled axial deformation up to final separation could not have been established.
With the help of the Stevin working group on measurement techniques a con-
trolled deformation up to failure could be realized using fast feedback control.
Additionally the geometry was optimized.

Dealing with the tensile behaviour of concrete led to an intensive preoccupation
with fracture mechanical problems. Reinhardt, who was following courses earlier
in Stuttgart on linear fracture mechanics of steel, transferred his ideas to concrete

Fig. 3. Reinhardt giving his inaugural lecture at TU Delft in 1976
cumulating in the article “Maßstabseinfluss bei Schubversuchen im Licht der Bruchmechanik” (“Size effect at shear experiments in the light of fracture mechanics”, [Reinhardt 1981]). About the same time, Arne Hillerborg introduced the “fictitious crack model” [Hillerborg et al. 1976], what resulted in the non-linear fracture mechanics. Zdenek P. Bazant derived the size effect law using linear theories in combination with the actual concrete behaviour [1976]. Reinhardt worked in this field together with Dutch colleagues at the Technical Universities Delft and Eindhoven, the TNO (Netherlands Organisation for Applied Scientific Research Building and Construction Research), RWS (Rijkswaterstaat) and CUR. At these days finite element techniques became more and more popular being applied to material problems in Civil Engineering. In this environment TU Delft was about to care for the material laws based on data of numerous experiments using regular, light-weight and fiber concrete and varying deformation velocities as well as the temperature. Additionally long term tests were conducted and the low cycle fatigue behaviour was examined. There was additionally a close cooperation with the Technical University in Darmstadt and different Universities in the US and Belgium.

Right at the beginning of his work in Delft it was discussed why precast piles got eventually damaged during driving. One possible explanation was that the pressure wave caused by driving converted at the end of the pile into a tension wave causing failure due to traction. His experiences with wave propagation effects during his visit in Chicago helped him to understand these phenomena including investigations of all parts of the system like pile drivers, the pile itself or an interface between both. An unknown parameter was the concrete and in particular the influence of the load velocity to its tensile strength, which was subject of a larger research project. After many experimental iterations the so-called „Split Hopkinson bar“ was chosen for a test setup. This method is based on the propagation of longitudinal stress waves in elastic bars. When a striker, accelerated typically to a velocity of 2.5 to 40 m/s, hits the front end of the incident bar, a compressive stress wave is generated, which propagates in the bar until it reaches the interface of the incident bar with the specimen. At the interface, part of the stress wave is reflected back as a pulse of tension, while the remaining part is transmitted through the specimen to the transmitted bar. A vertical test setup of 11 m high was implemented where at one end a tensional wave was generated by a drop-weight. After passing the incident bar out of aluminium the wave hit the concrete specimen. The load velocity was controlled by the interface between the weight and the aluminium bar. With this unique device numerous experiments were conducted to test regular, light-weight and fiber concrete whereas the composition as well as the ambient humidity and temperature were varied again [Reinhardt 1982]. The temperatures chosen went to extremes, i.e. down to –160° C for example, to investigate conditions similar to liquefied gas tanks.

In addition to these main research projects Reinhardt worked on the creep behaviour of regular and light-weight concrete in air and see water, on erosion of concrete in floating waters and shear load bearing behaviour of steel reinforced and prestressed concrete elements.
In 1986 Reinhardt got the offer to take over the chair of the Department of Construction Materials and Building Physics at the Technical University of Darmstadt and went back to Germany. At those days the German Federal Water Act (Wasserhaushaltsgesetz, WHG) was amended stipulating all chemical companies to proof that their plants do not pollute the groundwater. This included providing evidence of a secondary barrier system for storage systems protecting against water pollutants. To use retention basins out of concrete was common, but no one knew if this material being somehow porous was adequate. In cooperation with a large chemical company the penetration of fluids like gasoline, light and heavy fuel as well as ammonia was quantitatively evaluated. He took over two PhD students from his successor, Prof. Karl Weigler. One of the students was involved with partial area loading of concrete and the other just started to work on permeability of concrete. Reinhardt was interested primarily in the latter, because it dealt with the physical properties of concrete. This lead to a permeability prediction model subjected to
the pore radius being of help also for the prediction of penetration depths of organic fluids [Reinhardt & Gaber 1990]. Additionally, Reinhardt elaborated a concept to use computer based expert systems to assess near surface deteriorations of steel reinforced concrete structures. This resulted in the software REPCON being widely distributed but was suspended later, because the shell was not maintained anymore. SIFCON (Slurry Infiltrated Fiber Concrete) was a new highly ductile construction material developed in the United States but its other physical properties were generally speaking unknown. Reinhardt conducted tensile and shear load experiments. Coincidentally Antoine E. Naaman from the Michigan University, USA, was present as a visiting professor for several months in Darmstadt supporting him in his efforts. An extensive test series was conducted including the mechanical behaviour as well as the permeability in regards to organic fluids. 1990 was the year of the first workshop on "High performance fiber reinforced cement composites" (HPFRCC) in Mainz followed by four other workshops about this subject in later years either in Ann Arbor, Michigan, or Mainz. The next HPFRCC workshop (no. 5) is planned for July 2007 in Mainz and will be – of course – organized by Prof. Reinhardt.

**Stuttgart: April 1990 – March 2006**

In 1990 Reinhardt finally got a call back to his roots. He became full professor (Ordinarius) of the Department of Construction Materials of the University of
Stuttgart in association with the position of a director of the Forschungs- und Materialprüfungsanstalt Baden-Württemberg (Research and Material Testing Institute of the State of Baden-Württemberg). He followed Prof. Gallus Rehm (Fig. 5), who held these positions from 1973 to 1990 (see section Stuttgart: October 1970 – September 1975). Reinhardt was very active in these 16 years which requires a more detailed subdivision of this period.

**Non-destructive Testing in Civil Engineering**

1990 was also the year when the author met Reinhardt for the first time. Reinhardt had an interest to improve the methods of non-destructive testing (NDT) in Civil Engineering and initiated a new NDT working group (Fig. 6).

These efforts were supported by a new Collaborative Research Center (Sonderforschungsbereich 381) funded by the DeutscheForschungsgemeinschaft (DFG) and dealing with Characterization of Damage Evolution in Fiber Reinforced Composites by NDT. Besides the investigations of the crack initiation and propagation in concrete the NDT working group evaluated methods to monitor the setting and hardening of concrete. Starting from scratch the group developed under Reinhardt’s supervision a method based on ultrasound to be applied for quality control of fresh cementitious materials. This technique was later patented for Germany and the US [Reinhardt et al. 2003]. In 2000 a RILEM technical committee „Advanced testing of cement based materials during setting and hardening” was founded with Reinhardt as chairman. The TC was working on NDT methods to investigate the hardening of concrete bringing experts from all over the world together. An international workshop in Stuttgart 2006 as well as a book including a state-of-the-art report [Reinhardt & Grosse 2006] were the results of this TC. Regarding the fracture techniques Reinhardt – together with PhD students – applied methods known from geophysical prospecting to problems dealing with much smaller specimens, e. g. out of fiber reinforced and steel reinforced concrete. The acoustic emission technique was enhanced by a more signal-based data processing enabling for the analysis of data in respect to a correct 3D localization of cracks and a fracture mechanical interpretation of acoustic events. The theory (e. g. moment tensor inversion techniques) was adjusted to problems in Civil Engineering.

![Fig. 6. The NDT group in 2004](image)
taking certain wave propagation effects into account. Later on a DFG Research Group (netzgestütze Forschergruppe 384) was established by the DFG bringing together scientists from different German Research Institutions to work on the Non-destructive evaluation of concrete structures using acoustic and electro-magnetic echo-methods. Again Reinhardt was the chairman (Sprecher) of this group and Stuttgart’s NDT team developed a modified Impact-Echo technique to be applied to hardened and hardening concrete elements. Impact-Echo became one of the first modern NDT techniques in Germany to be included in a quality assurance standard (here: detection of a reduced thickness of concrete tunnel walls).

In addition to concrete Reinhardt was interested more and more in wood as a construction material. Already during his second Stuttgart period he published a paper about creep of wood. And it was natural that he got involved in the years following 1990 in the Collaborative Research Center 230 “Natürliche Konstruktionen” (Natural Structures) responsible for a project about fracture mechanics of wood. During the SFB381 (see above) wood became again an important issue concerning the fiber matrix interaction and NDT. Some work was done regarding the anisotropic behaviour of wood, the size effect law and the behaviour under humidity and temperature variation. Finally, the shear behaviour of glulam girders with openings was investigated.

Textile Reinforced Concrete

Another subject Reinhardt was working on was textile reinforced concrete. This material is still en vogue and Reinhardt was at the research forefront at that time again. Besides of large research projects at the Universities in Aachen and Dresden he succeeded to seize a niche: Prestressed textile reinforced concrete. The advantage of prestressed elements is that fabrics can be stretched first of all in weft direction and will not be elongated too much at the first sight of cracks. The experimental work was supported by know-how collected during the membrane experiments earlier as well as by a load device similar to the one earlier mentioned by Losch, but larger.

Civil Engineering in the Environment

To work with environmental issues in a broad sense was also one of his foci. This included investigations dealing again with the penetration of organic fluids into concrete, where Reinhardt was involved with the standardization of test methods, the expansion of the theory, penetration through cracked concrete and the modelling of the sequential penetration of two different fluids. In the frame of the RILEM organization a successful international collaboration led to the book “Permeation and permeability of concrete – Barriers to organic and contaminating liquids” [1997].

Another one of his topics dealing with the environment was the collaborative project Baustoffkreislauf im Massivbau (BIM) (Recycling of Construction Mate-
rials), where he was involved with the recycling of light-weight concrete. In addition a data base was created to collect the data of all collaborators. The software-based information system “B-I-M online” was established still available in the internet (http://www.b-i-m.de/, in German only).

In a third environmental topic he made enquiries on sustainable constructions using concrete. After compiling a state-of-the-art report another data base was established in a cooperative development, which is the basis of a new and ongoing project.

Finally, Reinhardt was involved with the problem of underground storage tanks for warm water. He was interested in the use of high performance concrete and its permeability for hot water and steam of up to 80° C. Experimental work was done including the design of a suitable measuring device as well as theoretical work to enhance the theory of temperature dependent transport of water and steam.

**Special Concrete and its Properties**

Despite of the earlier mentioned concrete research programs Reinhardt conducted on steel reinforced, fiber reinforced and textile reinforced concrete he was involved with hybrid concrete and self compacting concrete (SCC). Hybrid concrete consists of a larger part of normal aggregates and in addition a smaller part of light-weight aggregates. The water-saturated light-weight aggregates can take care of the internal hydration of concrete if highly dense concrete is used where a normal hydration process is difficult to be enforced from outside. Instead of light-weight aggregates super absorbing polymers (SAP) can be used. After preliminary results these investigations are ongoing. Compiling a guideline for the use of SCC it became evident that issues regarding heat treatment, fire resistivity and rheology are not fully covered. All three issues were investigated in Stuttgart with the effect that the SCC guideline is now better confirmed and the public use of SCC is safer.

Creep and shrinkage of concrete are well-known effects, but during experiments on high-performance concrete and SCC an additional effect was found called stress-induced shrinkage: The shrinkage effect of concrete is more evident if the material is subjected to stress.

**Memberships and Distinctions**

This compilation is giving certainly a poor overview if one does not mention the committee work Prof. Reinhardt did over the years in many national and international committees. Prof. Reinhardt is a member of numerous organizations including – among others – the *International Union of Laboratories and Experts in Construction Materials, Systems and Structures* (RILEM), the *American Concrete Institute* (ACI), the *American Society for Testing and Materials* (ASTM), *Deutscher Ausschuss für Stahlbeton* (DAfStb), *Deutscher Beton- und Bautechnikver ein* (DBV), *International Federation for Structural Concrete* (FIB), *Internationale
Vereinigung für Brücken- und Hochbau (IABSE) and the European Committee for Standardization (CEN).

Since several TCs were already mentioned in the text above where Reinhardt served as a chairman it would extent this article outmost to include a full list – this list would also not be complete since he is still very active in committees.

He was given many distinctions including the RILEM Fellowship (09/2000), the ACI Fellowship (04/2005). Since 2006 he is one of fourteen RILEM Honorary Members worldwide. In 2000, he was Visiting Professor at Southeast University, Nanjing, China, 2002 he got a Honorary Professorship from Dalian University, Dalian, China and in 2004 he received an Honorary Doctor from University of Technology, Braunschweig, Germany.

Conclusions

The results of Reinhardt’s research were obtained in most cases by the support of colleagues, Diploma and PhD students, assistants or other coworkers. However, some of his probably most characteristic qualifications were the ability to bring people with different scientific background together, to work on new solutions and to push the developments to the most successful direction. Moreover, his quiet and deliberated character was the basis for much collaboration. It might be also the main reason that he was a demanded consultant of projects.

This book brings together not only papers of some of his collaborators who will come together during the ACM2007 symposium. It will demonstrate also in which directions his ideas were developed.
Acknowledgements

The author is grateful for the support of Mrs. Jutta Reinhardt and her input to this article providing photographs.

The author dedicates this article to Prof. Hans-Wolf Reinhardt recognizing his fundamental work in particular in the field of non-destructive testing and to honor his advice and cooperation throughout the years.

References


Towards a better visibility of outstanding research

Michel Brusin¹, Matthieu Duvivier²

¹ Michel Brusin, RILEM, Bagneux, France (michel.brusin@rilem.org)
² Matthieu Duvivier, RILEM Publications, Bagneux, France
(matthieu.duvivier@rilem.org)

Abstract

After a brief introduction of the mission of RILEM, this paper describes the facilities offered by the new RILEM web site, for having the contributions from scientists and engineers more visible, and freely available to the international scientific community.

The optional free download option – implemented in October 2006 – proposed to the visitors of the RILEM website with the financial support of institutes and companies, is a completely new economic model, which will result very quickly in a much wider dissemination of the scientific articles available at www.rilem.net.

A practical example is given for RILEM Report 31 [1] produced by RILEM TC 185-ATC “Advanced testing of cement based materials during setting and hardening”, published online in September 2005, which electronic edition is available for free to each researcher or engineer in the world.

1. The mission of RILEM

The International Union of Laboratories and Experts in Construction Materials, Systems and Structures (RILEM, from the name in French) was founded in June 1947, with the aim to promote scientific cooperation in the area of construction materials and structures.

Today, the new meaning of the acronym RILEM (Réunion Internationale des Laboratoires et Experts des Matériaux, systèmes de construction et ouvrages) emphasizes its dominant focus on people as well as its worldwide activities, covering 70 countries.
The mission of the association is to advance scientific knowledge related to construction materials, systems and structures and to encourage transfer and application of this knowledge world-wide. This mission is achieved through collaboration of leading experts in construction practice and science including academics, researchers, testing laboratories and authorities.

The three main goals of RILEM are:

- to promote sustainable and safe construction, and improved performance and cost benefit for society,
- to stimulate new directions of research and its applications, promoting excellence in construction,
- to favor and promote cooperation at international scale by general access to advanced knowledge.

Our worldwide goals are:

- to promote environmental friendly, safe and sustainable construction
- to improve performance and cost benefit for users and general public
- to engage top experts of construction practice and in science as well as promising young scientists and engineers
- to involve a broad range of players including academics, researchers, testing laboratories, suppliers, contractors, owners and authorities
- to ensure networking
- to promote education and training
- to encourage the formation of active regional groups
- to provide a platform of experts in interdisciplinary terms
- to stimulate new orientations of research and application
- to promote and maintain excellence in research and technology
- to prepare and widely disseminate outstanding RILEM products such as guides to good practice, recommendations (and if required also pre-standards), proceedings of symposia and workshops, state of the art reports, data basis, and International Journals.

2. The three steps of information

RILEM is dedicated to contribute to the progress in the construction sciences, techniques and industries, essentially by means of facilitating communication between research and practice. RILEM dissemination of knowledge can be considered as a 3-phase process:

*Meeting together:* RILEM members meet together in many circumstances, and in particular:
Towards a better visibility of outstanding research

- during international RILEM events: workshops, seminars, conferences
- through meetings of the best international experts working together and sharing their expertise and knowledge in RILEM Technical Committees (TCs)

Producing the information: if meeting together is a starting point, then the TC is responsible, under the leadership of the chairperson, for preparing working documents which are discussed during the lifetime of a TC, resulting in
- testing methods concerning a specific characteristic of a building material
- a state-of-the-art report on the subject treated by the TC.

Spreading the information: Producing the information is of major importance for those scientists and engineers actively contributing to the TC work. The final resulting products also have to be widely disseminated through appropriate access to RILEM members (even those not directly involved in the TC work), and in a second step through general access to the public.

The final products of a TC work These final products, combined with the proceedings of workshops and conferences organised by the TCs, follow other immediate reports on on-going activities, which are mentioned in our annual report and presented in more details in our scientific journal, Materials and Structures, combined with the proceedings of workshops and conferences organized by the TCs, follow other immediate reports on on-going activities, which are published in our scientific journal, Materials and Structures.

3. Increased visibility of RILEM publications

3.1 The different types of publications

During the recent 5 past years, RILEM considered different options for an enhanced dissemination of outstanding research. This is in fact a permanent concern, for which different actions are decided when appropriate. But first let us come back quickly to the production of RILEM.

RILEM Technical Recommendations

Over 200 RILEM Technical Recommendations have been produced by RILEM Technical Committees. Many of these recommendations have been adopted in research and practice, and are used by international standardization bodies, as a basis for their work.

State of the Art Reports

These reports constitute a critical appraisal of current knowledge on a specific research subject. They often identify gaps in knowledge, thereby contributing to the development of strategies and scenarios for future research.
RILEM Journals

The RILEM flagship publication is “Materials and Structures / Matériaux et Constructions” (M&S). Since 2006, M&S is published by Springer, for a wider visibility. With 10 issues a year, it is a leading international journal, publishing results of current research on the properties and performance of building and structural materials, standardization of test methods and the application of research results. Another scientific journal has been created by RILEM in 1999, Concrete Science & Engineering (CSE), for creating a bridge between research and practice [2]. During the period 1999-2002, CSE published outstanding articles and special issues on different topics, thanks to the personal endeavor of the Board of Editors (Suru Shah, Hans Reinhardt, Francis Young and Jacques Marchand) and of the Editorial Advisory Committee. Any of these published articles is now available online at www.rilem.net. For a wider audience and exposure, CSE has been merged with M&S (in Fall 2002), with special thematic issues of CSE still published quarterly in M&S between 2003 and 2005.

Symposia and Workshops

RILEM has been organizing symposia and workshops since its foundation, with more than 100 proceedings published. A quick glance at our online catalogue shows the diversity, importance and international scope of the topics, which can be classified in 5 different clusters (as it is the case for the different active RILEM Technical Committees):

- Mechanical Performance and Fracture
- Materials Characterization, Properties Evaluation and Processing
- Design and Service Life
- Performance and Deterioration Mechanisms
- Special Construction Materials and Components.

3.2 RILEM online publications and DOI

In April 2004, RILEM Publications joined PILA, a non-profit making Association created in 2001 by international large publishers for cross-reference linking of their publications. The spirit of the DOI (digital object identifier) is to assign a permanent identification code to any article published online, which results in a permanent linking to this article, even in case the URL for reaching this article can be changed. This use of DOIs by RILEM has been implemented for both our journals, and for our online reports and proceedings. As regards our scientific journal Materials and Structures, the use of a DOI for each original article published online resulted in a major increase of the impact factor of the journal between 2004 and 2005 (IP multiplied by 2.26 between 2003 and 2005).