OVERVIEW OF THE IWB ACTIVITIES ON THE FIELD OF NON-DESTRUCTIVE TESTING

ÜBERBLICK ÜBER DIE AKTIVITÄTEN DES IWB AUF DEM GEBIET DER ZERSTÖRUNGSFREIEN PRÜFUNG

APPERÇU DES ACTIVITÉS DE L'IWB DANS LE DOMAINE DES ESSAIS NON DESTRUCTIFS

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ABSTRACT

During the last decade the non-destructive testing (NDT) of building materials became one of the priorities of the division *Materials and Construction* of the Institute of Construction Materials (IWB) of the University of Stuttgart. Several research projects have been funded by the Deutsche Forschungsgemeinschaft DFG (German Research Council) increasing the number of scientists and technicians involved with NDT significantly. Four different fields of interest can be subdivided more or less correlated each with certain grants. This paper deals with the objectives of these projects.

ZUSAMMENFASSUNG

In den letzten zehn Jahren wurde das Arbeitsgebiet „Zerstörungsfreie Prüfung von Baustoffen" zu einem der Schwerpunkte der Abteilung Werkstoffe und Konstruktion des Instituts für Werkstoffe im Bauwesen (IWB). Es gelang, eine Reihe von Forschungsprojekten einzuwerben, so dass mittlerweile auch personell die Gruppe einen vergleichsweise großen Umfang hat. Es lassen sich vier Projektbereiche unterscheiden, die teilweise direkt mit entsprechenden Drittmittelprojekten verbunden sind. Um eine Übersicht zu geben, werden im folgenden die Ziele dieser Projekte beschrieben.

RESUME

Au cours de la dernière décennie, le champ d'activité "essais non destructifs sur les matériaux de construction" est devenu l'un des principaux axes de recherche du département *Matériaux et Constructions* de l'Institut des Matériaux du Génie Civil (IWB) de l'université de Stuttgart. Plusieurs projets de recherche sont soutenus par la Deutsche Forschungsgemeinschaft DFG (Conseil de Recherche Allemand), ce qui a mené à une augmentation sensible du nombre

de scientifiques et de techniciens impliqués. On peut distinguer quatre centres d'intérêt, chacun plus ou moins directement corrélé à une bourse de recherche. Cet article traite les objectifs de ces projets.

KEYWORDS: Non-destructive testing; Ultrasound; Acoustic Emission; Impact-Echo.

SUBPROJECT A6 IN THE SFB 381

In 1994 the collaborative research centre *Characterization of failure process in fibre reinforced materials using non-destructive testing methods* was established at the University of Stuttgart. Getting a positive evaluation by the DFG in spring 1997 and again in May 2000 for the next period the project is now in its third 3-year term (2001-2003). In subproject A6 the capabilities of non-destructive testing methods dealing with *Detection and localization of defects in steel and steel fibre reinforced concrete* (title of this subproject) are evaluated.

The intention for this project was the analysis of the failure process in steel- and steelfiber-reinforced concrete. Investigations focussed on the bond between the reinforcement and the concrete as well as on the non-destructive testing methods (Acoustic Emission Technique, AET, and Impact-Echo) capable to detect faults and failures in concrete in terms of pull-out and bending tests. Further on, the understanding of failure mechanisms can be enhanced using a FE-modelling approach based on micro-physical techniques in collaboration with subproject C2 (Institute of Static and Dynamic of Aerospace Structures – ISD). The comparison of the results for the failure process based on FE calculations together with the AET results from real experimental data is done in close cooperation using a visualisation software made by ISD. This software is an essential tool for the teamwork. The AET results are obtained during pull-out tests, for instance, and are analysed by means of inversion techniques used to localize and specify the AE signals. The moment tensor technique is able to extract the fracture type, the radiation pattern (orientation of the fault plane) as well as the seismic moment, which is related to the emitted energy [Grosse 1996, Grosse et al. 1997] out of the recordings of acoustic emission at different sensors (fig. 1).

Other research activities are focused on the investigation of the bond between steel or steel fibers and the concrete matrix in three point bending tests using cyclic and long term load, the advancement of localization and inversion

techniques in quantitative acoustic emission analysis, the use of other NDT methods like the radiographic CCD and the Impact-echo technique as well as the ultrasonic sound transmission spectroscopy in co-operation with the project partners.

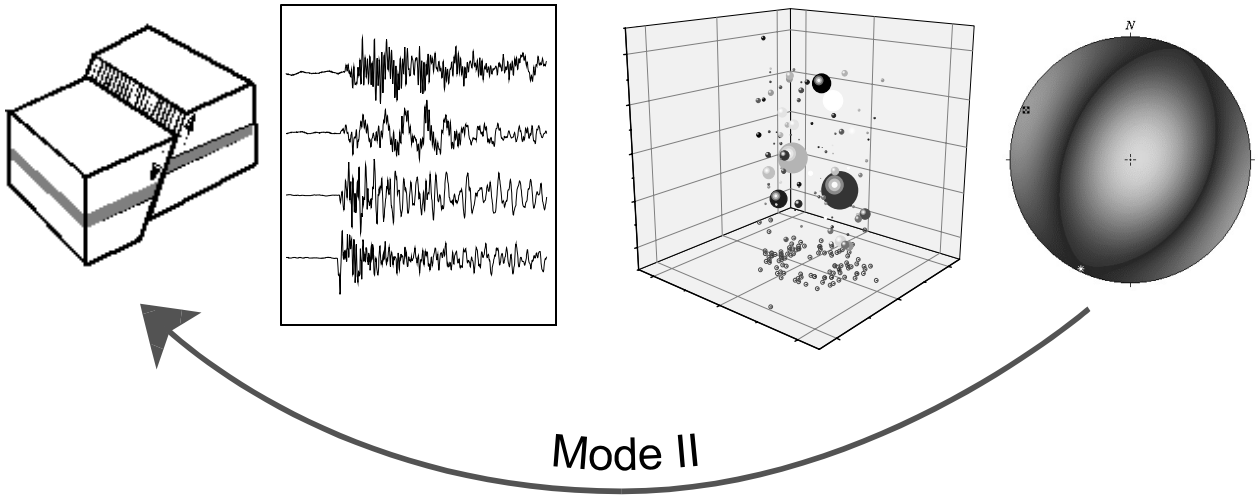

Figure 1: Example of the application of inversion techniques in acoustic emission analysis.

To enhance the capabilities of automatic data processing in acoustic emission and ultrasound analysis an algorithm was developed to identify (pick) the first arrival times of signals at a certain sensor used in AET and ultrasound (B- and C-sans) experiments. This program is called **WinPecker** [Grosse 2000] and is distributed via the *Technology Licence Bureau* GmbH in Karlsruhe. Details of this software as well as information about the project and other activities can be found at the following homepage (http://iwb.uni-stuttgart.de/grosse/grosse.htm) or in the literature. You can also have a look at the URL of the SFB 381: http://sfb381.uni-stuttgart.de/ for more information.

Two reports printed by the Sonderforschungsbereich 381 (collaborative research centre 381) summarizes the results of the first two three-year terms [Reinhardt et al. 1997 & 2000]. Information about the current research activities can be obtained from the contributions in this report as well as in the Otto-Graf-Journal.

The scientific responsibility for this project is with Prof. Dr.-Ing. H.-W. Reinhardt and Dr.-Ing. Chr. U. Grosse; with the realisation of the research plan Dipl.-Geophys. F. Finck and Dipl.-Phys. M. Jarczynski are entrusted. The technicians G. Bahr, H. Nörren and G. Schmidt are supporting the project.

SUBPROJECT A9 IN THE SFB 381

For the third three-year term of the SFB 381 there was a proposal for a new subproject entitled *Quantitative damage evaluation of fibre composites with mineral matrix using ultrasound;* subproject A9 started at the 1.1.2001.

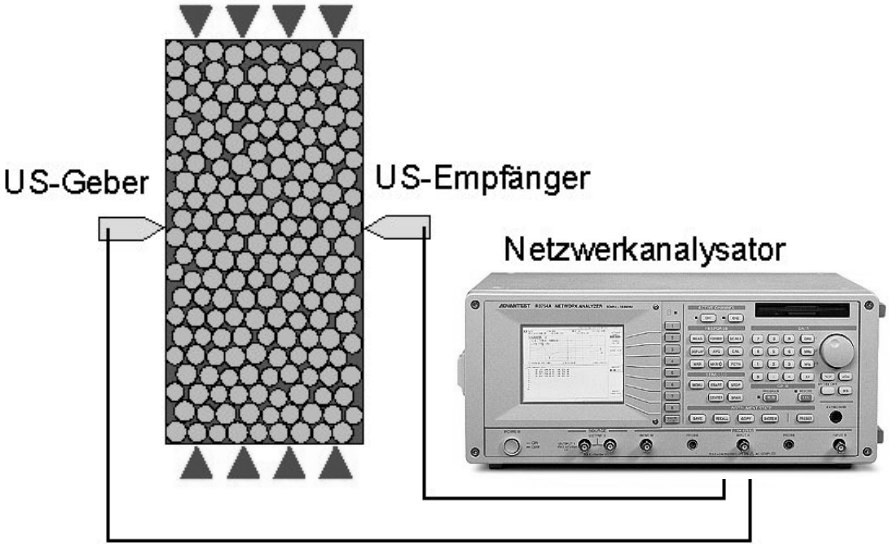

Figure 2: Setup for crack evolution in monosize concrete under load using a network analyser.

Composite materials with mineral matrix are widely used in civil engineering, i. e. all kind of fibre reinforced materials as well as mortars, natural and artificial building blocks and ceramic materials. Of interests are also high-performance ceramics used in aerospace or innovative motor concepts – those materials are also based on mineral matrix composites. The mix of the single components as well as the bond between them are properties, which influence the damage and failure of materials in service.

Regarding the non-destructive testing mainly ultrasound methods, especially the through-transmission spectroscopy, is applied. Sensors (piezo-ceramics) are attached for through-transmission experiments during the uni-axial load of concrete specimen. The ultrasound signals subjected to analysis are obtained using a network analyser (fig. 2) in through-transmission. The travel time as well as amplitude and frequency content is examined using wavelet techniques depending on the stage of load during the pressure tests. The results of the non-destructive measurements are compared with the information obtained by strain gauges. Parameters to be varied or analysed are stress, deformation or crack opening displacement, wave velocities, amplitude decrement, frequency content, material composition, type and content of fibres.

It is expected that these parameter studies allow a unique approach to the study of damage evaluation in materials using ultrasound techniques. As an additional measurement tool AET is applied to correlate the results of ultrasound with local damages using localization and moment tensor inversion techniques.

The scientific responsibility for this project is with Prof. Dr.-Ing. H.-W. Reinhardt and Dr.-Ing. Chr. U. Grosse; with the realisation of the research plan Dipl.-Phys. H.-J. Ruck is entrusted. The technicians G. Bahr, H. Nörren and G. Schmidt are supporting the project.

COLLABORATIVE RESEARCH INITIATIVE (FORSCHERGRUPPE) 384

The target of this research initiative of the DFG dealing with methods to investigate concrete components and its structures with non-destructive testing methods is to enhance the test capabilities for on-site inspections to a level of systematic and routine application of validated diagnostic procedures. The so far isolated development of testing methods should be consolidated in a long-term cooperation of working groups to push their innovation. First step is the evaluation of the existing acoustic and electromagnetic procedures and their combination to understand the processes and interactions in order to place the methodology of such investigations on a verifiable scientific base. In detail are this apart from the combination of several procedures, the integration of simulation and modelling as well as the development or advancement of new procedures e.g. air ultrasonic, group emitter, scanning impact-echo etc.

The eight institutes participating in this research initiative are accompanied by a supporting group consisting of six federal departments or private companies, which are not funded by the DFG. The “Forschergruppe 384” was established by the DFG beginning its work at 1.1.2001.

To give an overview (tab. 1) the members of the *Forschergruppe* as well as the members of the supporting group are compiled in the following list (valid as per 1.9.2001). Scientific director of the FOR 384 group, is Prof. Dr.-Ing. H.-W. Reinhardt, Dr.-Ing. Chr. U. Grosse is acting as a managing director. The members are distributed throughout Germany, while communication is done using present internet technology like WWW- and FTP-servers, Email etc.

Table 1: Members of the Collaborative Research Initiative FOR 384 of the DFG.

Bundesanstalt für Materialforschung und –prüfung (BAM)
Unter den Eichen 87, 12205 Berlin
Fachgruppe IV.4: Zerstörungsfreie Schadensdiagnose und Umweltmessverfahren
Dr.rer.nat. Herbert Wiggenhauser, Dr. Martin Krause, Dr. Christiane Maierhofer

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Prof. Dr.rer.nat. Karl-Jörg Langenberg, Dr.-Ing. Klaus Mayer

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Dipl.-Ing. C. Flohrer

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Robert-Bosch-Strasse 3, 50354 Hürth (Efferen)
Dr. W. Roye

Polytec GmbH
Polytec Platz 1-7, 76337 Waldbronn
Dr. Siegmund

SUBPROJECT VIII OF THE *FORSCHERGRUPPE 384*

Besides the „Z project", where Reinhardt and Grosse are acting as scientific or managing director resp., the DFG also granted a new subproject VIII located at the Institute of Construction Materials of the University of Stuttgart; it is called *Determination of structures of hardening reinforced and unreinforced concrete elements with a modified Impact-Echo-System.*

The main purpose of this project is the improvement of the impact-echo technique (fig. 4) and it's applicability for testing concrete structures. Primarily the application of the method in terms of fault and fracture localization as well as for thickness measurements in tunnels for instance is evaluated. The issue of a guideline for the use of impact-echo in quality control of all tunnels in the frame

of constructions by federal institutions in Germany written by the ministry of transportation, building and housing is a booster for the application of this technique in-situ.

A second field of interest is the use of impact-echo for the control of concreting during hardening and setting using a modified measuring device. This means the evaluation of both, thickness and stiffening of the material, in-situ to enhance the efficiency of concreting in terms of time, material and first of all money. Doing it in this way would have numerous applications for instance in shotcreting using steel fibers, the production of industrial floors or manufacturing of prefabricated or prestressed steel concrete elements at the factory or on site.

The scientific responsibility for this project is with Prof. Dr.-Ing. H.-W. Reinhardt and Dr.-Ing. Chr. U. Grosse; with the realisation of the research plan Dipl.-Ing. R. Beutel is entrusted. The technicians G. Bahr, H. Nörren and G. Schmidt are supporting the project.

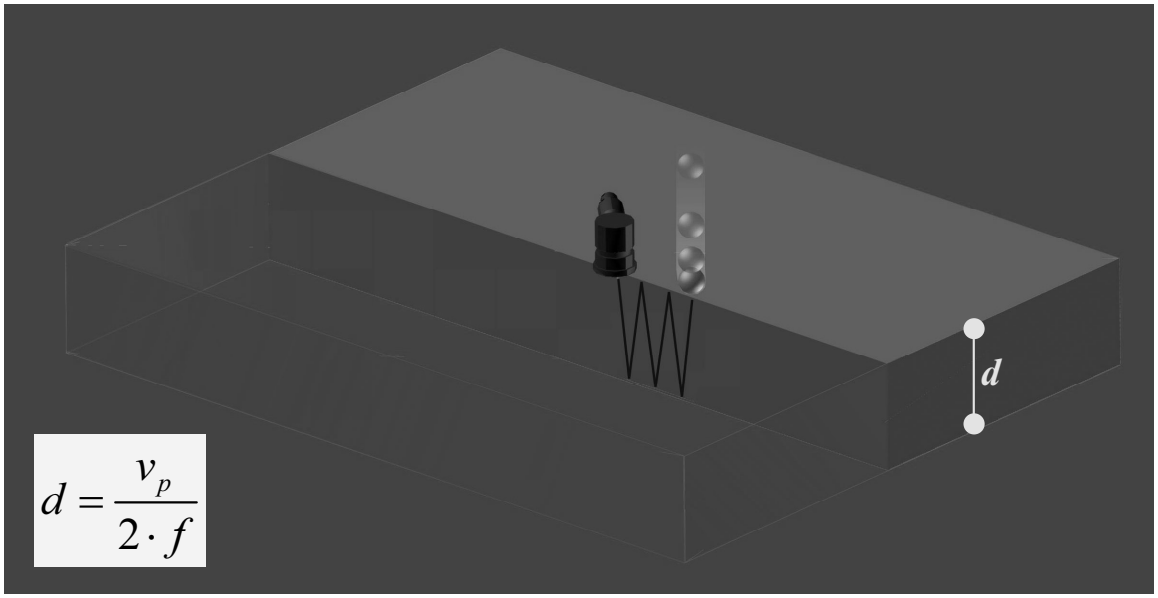

Figure 4: Example of a setup for impact-echo measurements. The wave emitted by the impact is reflected at boundaries and recorded by the sensor. The thickness of the layer is calculated analysing the wave in frequency domain using the formulation above.

QUALITY OF CEMENTITIOUS MATERIALS USING ULTRASOUND

In the last ten years a testing method based on ultrasound was developed at the IWB to control the hardening process of cementitious materials by means of non-destructive testing. With the ultrasound technique amplitude-, velocity- and frequency-variations depending on the age of the material can be observed. The property of cementitious materials are changing from a suspension to a solid during the stiffening process caused by the hydratation of the cement-matrix. Material parameters to be observed are for example the water to cement ratio, the type of cement, the use of additives like retarders, accelerators or air entrainers or the content of air bubbles. With the developed apparatus an operator is able to record single data as well as continuous data sets during hours or even days along with certain physical parameters correlated with the elastic properties of the material [Grosse & Reinhardt 2000a & 2000b].

To enhance the interpretation capabilities several parameters have to be extracted out of the recorded waves. For the determination of compressional wave velocities only the onset time of the signals is evaluated. Additional information can be obtained analysing the change of the signal, i. e. amplitudes or the frequency content, during the setting of the material. Again, it is useful to analyse the signals also in frequency-time-domain by a wavelet transform. For the automatic real-time extraction of the velocity, the energy as well as of the frequency the FreshCon2 program is used including a rapid first interpretation of material properties by a full-automatic determination of the initial and final setting time. Comparing the graphs recorded for different material compositions differences in quality as well as of the workability can be found easily.

Using the described approach to material characterization numerous applications can be made. For the materials producers the effect of admixtures and additions on the fresh or the hardened state of concrete or mortar is of interest (fig. 5). Other possible applications range from the quality control and time-optimisation techniques in concreting factories for finished parts to the control of workability in an cost-effective environment in-situ.

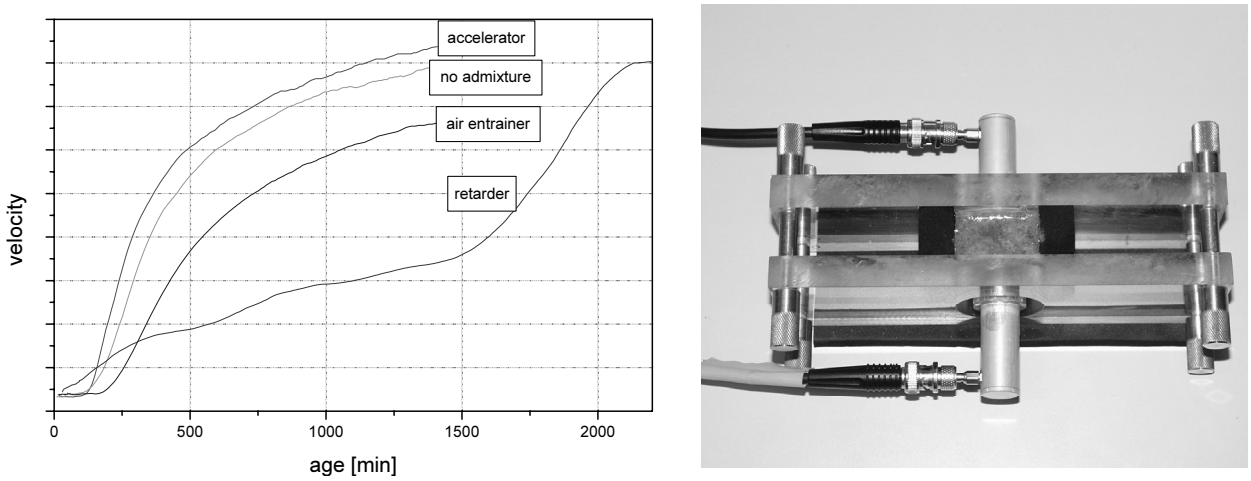

Figure 5: Example of the effect of concrete additives analysed using ultrasound (left). Setup using the ultrasound device of the IWB, Stuttgart (right).

In 1999 a Rilem Technical Committee ATC (*Advanced testing of cement-based materials during setting and hardening*) was founded. The chairman is Prof. Dr.-Ing. H.-W. Reinhardt, while Dr.-Ing. Chr. U. Grosse is acting as a secretary. In this TC the applicability of this method is investigated by round robin tests in comparison with other measurement devices. A first series of tests was conducted in collaboration with the *Ecole National des Travaux Publics de l'Etat* (ENTPE) in Vaulx-en-Velin near Lyon (France). More are to come during 2001 collaborating with the *Fraunhofer Institute of Non-destructive Testing* (IzfP) in Saarbrücken and the *Institute of Building Materials, Concrete Construction and Fire Protection* (iBMB) of the Technical University in Braunschweig (Germany).

SUMMARY

Under the supervision of Prof. Dr.-Ing. H.-W. Reinhardt and Dr.-Ing. C. U. Grosse a working group dealing with the development and application of non-destructive testing methods in civil engineering was established at the *Institute of Construction Materials* of the University of Stuttgart. The focus of this group is in the application of methods based on elastic waves like acoustic emission or impact-echo technique as well as ultrasound. There is a wide range of applications from fundamental research studying the material properties and the fiber-matrix bond under load to very practical solutions for quality control in-situ. The team, consisting of six scientific and three technical collaborators, is in fact one of the biggest groups on NDT in civil engineering in Germany. Scientific results can be obtained from other authors in this report or from the

internet via the web pages of the institute, where a list of publications is available.

ACKNOWLEDGEMENTS

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