BAM
Bundesanstalt für Materialforschung und -prüfung

Empa
Materials Science and Technology

DGZfP
DEUTSCHE GESELLSCHAFT FÜR ZERSTÖRUNGSFREIE PRÜFUNG e.V.

PROGRAMME & ABSTRACTS

SMAR 2019 Potsdam

SMAR 2019

5th International Conference on Smart Monitoring, Assessment and Rehabilitation of Civil Structures

27 – 29 August 2019 | Germany

Welcome to SMAR 2019 in Potsdam, Germany

SMAR 2019 is the fifth conference on Smart Monitoring, Assessment and Rehabilitation of Civil Structures to be held at Potsdam, Germany, from 27 to 29 August 2019, co-organised by Empa, the Swiss Federal Laboratories for Materials Science and Technology, Bundesanstalt für Materialforschung und -prüfung (BAM) and Deutsche Gesellschaft für Zerstörungsfreie Prüfung (DGZfP). It is a follow-up of the biannual successful SMAR conference series starting in 2011 in Dubai, 2013 in Istanbul, 2015 in Antalya and 2017 in Zurich. SMAR 2019 in Potsdam, Germany proceeds with presenting innovative materials and technologies for structural health monitoring as well as rehabilitation, such as application of Smart Fibre Optic sensors, Fibre Reinforced Polymers, Shape Memory Alloys, most recent advances in the application of Deep Learning and Data Science in Structural Engineering and much more.

As an interdisciplinary research institute of the ETH Domain, Empa, the Swiss Federal Laboratories for Materials Science and Technology, conducts cutting-edge materials and technology research. Empa's R&D activities focus on meeting the requirements of industry and the needs of society, and thus link applications-oriented research to the practical implementation of new ideas.

The Bundesanstalt für Materialforschung und -prüfung (BAM) is a senior scientific and technical Federal institute with responsibility to the Federal Ministry for Economic Affairs and Energy. BAM tests, researches and advises to protect people, the environment and material goods and sets and represents high standards for safety in technology and chemistry for Germany and for its global markets.

The German Society for Non-Destructive Testing (DGZfP) is a non-profit organisation and the body which coordinates all NDT activities in Germany. DGZfP has always attached particular importance to the training of NDT personnel. Courses and examinations are now held in nine NDT methods at three different levels. DGZfP also offers initial and advanced radiation protection training in accordance with the relevant guidelines.

Potsdam is one of the most attractive communes in Germany. The city is characterising by worldknown castles and gardens, arts and culture. Science and sports are integral parts of the capital of the federal German state Brandenburg. Numerous waterways und wide landscape and the vicinity to Berlin make Potsdam a never forgettable place. The Potsdam region is listed as UNESCO cultural heritage.

The conference is hosting 245 scientists and experts from around the world to present their solutions and findings in the following areas:

- Structural Health Monitoring
- Performance and damage assessment
- Damage control, repair and strengthening, fire protection
- Durability of material systems and structures related to harsh environment
- Non-destructive testing
- Practical applications and case studies
- Visionary concepts, deep learning

In addition to the regular sessions, several special sessions as follows were organised:

- Strengthening, Monitoring and Life-cycle Assessment of Metallic Structures
- Durability and Corrosion Monitoring of Concrete Infrastructures
- SHM between Research and Application: New Concepts for New Technologies
- Testing, Inspection, Monitoring and Repair of Offshore Wind Energy Converters
- Shape Memory Alloys (SMAs) for Engineering Applications

SMAR 2019 is sponsored jointly by the Bundesanstalt für Materialforschung und -prüfung (BAM), Swiss Federal Laboratories for Materials Science and Technology, Empa, Deutsche Gesellschaft für Zerstörungsfreie Prüfung (DGZfP), the International Society for Structural Health Monitoring of Intelligent Infrastructure (ISHMII), International Institute of FRP in Construction (IIFC), the Istanbul Technical University (ITU), Turkey, the International Association for Bridge Maintenance and Safety (IABMAS), International Union of Laboratories and Experts in Construction Materials, Systems and Structures (rilem) as well as Sensors – Open Access Journal and Materials – Open Access Journal.

The proceedings contain a total of 182 papers written by authors from around countries worldwide. The contributions include interesting Keynote Papers on condition assessment in reinforced concrete with or without FRP strengthening and bridge structures, near surface mounted technique, monitoring and UHPFRC technology, concrete bridges in China and seismic performance of existing structures.

We would like to thank all authors for preparing their work towards this compilation, which will undoubtedly serve as a useful reference to practitioners, researchers, students and academics and allied disciplines. Special thanks are due to Members of the International Scientific Committee, who reviewed the papers carefully. The support of the sponsoring organisations and companies is gratefully acknowledged. We are indebted to our colleagues in Organisation Committee. Thanks to the Empa, BAM and DGZfP conference team, Steffi Dehlau, Anne Zimmermann and Bernadette Havranek the conference secretaries, for their tireless efforts and quick responses to many demands of the conference.

We wish you a succesful conference and a good stay in Potsdam.

Rosemarie Helmerich (BAM), Masoud Motavalli (Empa) and Alper Ilki (ITU)
Co-Chairs, SMAR 2019, August 2019

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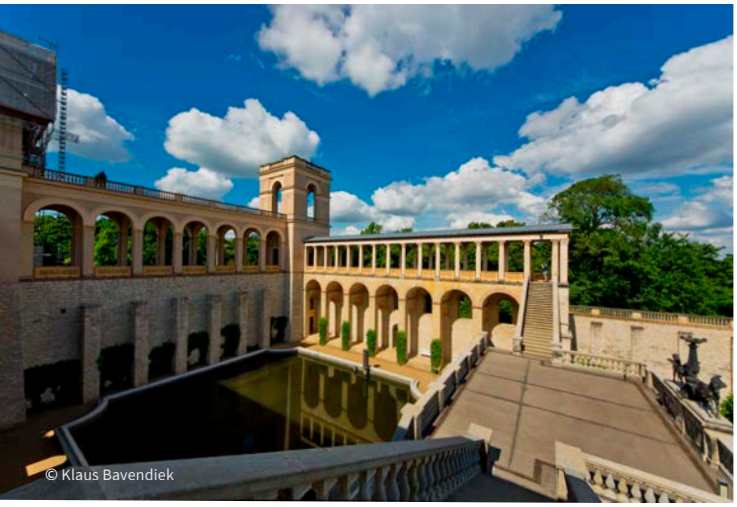
Organisation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BAM
Bundesanstalt für Materialforschung und -prüfung

BAM

The Bundesanstalt für Materialforschung und -prüfung (BAM) is a senior scientific and technical federal institute with responsibility to the Federal Ministry for Economic Affairs and Energy. It tests, researches and advises to protect people, the environment and material goods.
BAM sets and represents high standards for safety in technology and chemistry for Germany and for its global markets, to further develop the successful „Made in Germany“ culture of quality. BAM fulfils this role through its dedicated employees.
According to its founding decree, BAM is responsible for the

- further development of safety in technology and chemistry
- implementation and evaluation of physical and chemical tests of materials and facilities, including the preparation of reference processes and reference materials
- promotion of knowledge and technology transfer within the BAM‘s areas of work
- cooperation in the development of statutory regulations, for example concerning the setting of safety standards and limits
- advice to the Federal Government, industry, and national and international organisations in the fields of material technology and chemistry.

BAM is the successor organisation to the Staatliches Materialprüfungsamt [National Materials Testing Office], founded in 1871, and the Chemisch-Technische Reichsanstalt [Chemical-Technical State Institute], founded in 1920.
The Federal Institute for Materials Research and Testing integrates research, assessment and consultation in technology and chemistry under one umbrella.
Technological change is a guarantee for our society’s prosperity. New technologies are the basis for the successful development of Germany as a business location and for value creation in global markets. Sustainable safety of new technologies creates trust in change and secures our future.
At the cutting-edge of key technologies of materials science, materials engineering and chemistry, we make a crucial contribution to the technical safety of products, processes and to people’s life and work environment. For this purpose we carry out research and tests and provide advice based on our expertise and years of experience at the interfaces of science, technology, industry and politics.

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Empa

Materials and technologies for a sustainable future

As an interdisciplinary research institute of the ETH Domain, Empa, the Swiss Federal Laboratories for Materials Science and Technology, conducts cutting-edge materials and technology research. Empa's research and development activities focus on meeting the requirements of industry and the needs of society, and thus link applications-oriented research to the practical implementation of new ideas in the areas of nanostructured, "smart" materials and surfaces, environmental, energy and sustainable building technologies as well as bio-technology and medical technology.

The place where innovation starts

Through an efficient technology transfer Empa is turning research results into marketable innovations. As a result, Empa is capable of providing its partners with customized solutions that not only enhance their innovative edge and competitiveness, but also help to improve the quality of life for the public at large. Safety, reliability and sustainability of materials and systems are keys to all Empa activities. The Empa Portal is the central contact point for partners and customers who wish to start research projects in cooperation with Empa or who are seeking innovative solutions to specific problems. As part of the ETH Domain, Empa is committed to excellence in all its activities.

DGZfP

The desire to test materials and components without destroying them, namely in the manner which does not prejudice their subsequent use, is as old as the ability to manufacture them.
It is about 100 years since Wilhelm Conrad Röntgen discovered X-rays and performed experiments with photographic plates which laid the fundaments for the non-destructive testing applications of today. NDT has become a key safety factor. In similar fashion to diagnostics in medicine, it is designed to reveal hidden defects in components and designs both before and during operation and in this way to avoid unforeseen breakdowns and failures.
Almost all branches of industry have come to rely on NDT as a central instrument of quality control and quality assurance
X-ray methods, ultrasound, thermographic techniques, leak detection methods as well as optical, electrical and magnetic surface techniques are used in NDT to help prevent unforeseen accidents which may endanger human lives and cause extensive damage to property and the environment.
The German Society for Non-Destructive Testing (DGZfP) is the body which coordinates all NDT activities in Germany. DGZfP considers itself as an intermediary to translate research findings into practical application as well as for transferring difficult problems arising in industrial testing to interested institutes and equipment manufacturers. The DGZfP represents the members' interests in national and international bodies and presents awards for special achievements.
The training of non-destructive testing personnel is one of the tasks to which DGZfP devotes particular attention. With its extensive training programme, DGZfP is the largest training centre for NDT personnel in Europe. Training centres in Berlin, Dortmund, Hamburg, Magdeburg, Mannheim, Munich and Wittenberge give many companies the opportunity to complete a well-founded and practical training.
DGZfP and its committees hold conferences and conventions on all major methods and issues of non-destructive testing. The DGZfP Annual Conference is held in a different German city each year. Every four years a joint conference with the Austrian and Swiss NDT society is organised.

Institutional Sponsors

IABMAS

FIELD OF ACTIVITY

The Association encompasses all aspects of bridge maintenance, safety, and management. Specifically, it deals with: bridge repair and rehabilitation issues; bridge management systems; needs of bridge owners; financial planning, whole life costing and investment for the future; bridge related safety and risk issues and economic and other implications.

MISSION

The mission of the Association is to become the premier international organisation for the advancement of the state-of-the-art in the fields of bridge maintenance, safety and management.

OBJECTIVE

The objective of the Association is to promote international cooperation in the fields of bridge maintenance, safety and management for the purpose of enhancing the welfare of society.

ACTIVITIES

In order to fulfil its mission and objective, the Association will organise congresses, conferences, symposia, workshops, seminars, and short courses on the related topics. The Association intends to cooperate with other organisations including AASHTO, ACI, AISC, ASCE, CERRA, ESRA, FIB, IABSE, IALCCE, IASSAR, ICE, IFIP, JCSS, PIARC, and RILEM having interest in bridge maintenance, safety and management.

JOIN IABMAS

Membership fee for both individual and collective members is free! To apply to become a member of IABMAS, please provide all the information on the IABMAS website (www.iabmas.org).

NATIONAL GROUPS OF IABMAS

To better coordinate its activities, the International Association for Bridge Maintenance and Safety (IABMAS) provides the possibility of establishing national groups. At present (August 2019) there are nine national groups: Australia, Brazil, Chile, China, Italy, Japan, Korea, Portugal and Turkey.

IIFC

The aim of the International Institute for FRP in Construction (IIFC) is to advance the understanding and the application of fibre-reinforced polymer (FRP) composites in civil engineering infrastructure, in the service of the engineering profession and society. The objectives of the Institute are to:

(a) provide a focal point for international sharing of knowledge and experience;

(b) promote collaboration to maximise the benefit of the international research and development effort;

(c) foster international harmonisation of design and application standards;

(d) further the acceptance of FRP composites by the engineering community and beyond as a major construction material;

(e) advocate further innovations, particularly through the interfacing of FRP composites with other technologies such as intelligent sensing.

The Institute organises various activities in order to achieve its aim and objectives, including the acknowledgement of excellence through the IIFC Medal and the Distinguished Young Researcher Awards, Best Paper Prizes, and the Best PhD Thesis Award. Additionally, an important activity of the IIFC is the organisation and sponsorship of international conferences, symposiums, workshops, short courses and seminars, including two biennial official conferences (i.e. the CICE and FRPRCS conference series). More details about the IIFC can be found on its website www.iifc.org, where all IIFC conference proceedings can be downloaded for free.

The IIFC has sponsored all the SMAR conferences starting from the inaugural conference in 2011 in Dubai to this fifth instalment in Potsdam. On behalf of the IIFC, I would like to congratulate all the past and present organisers of this conference series for their professional organisation. Best wishes to all delegates for a most fruitful conference and enjoyable time in Potsdam!

ISHMII

ISHMII advances our understanding and the application of SHM methodologies for the condition assessment and management of civil infrastructure systems. ISHMII shares the knowledge and experience in technologies impacting Civil Structural Health Monitoring (CSHM); including sensors, instrumentation, monitoring strategies, data mining, management, and interpretation for decision-making processes, case studies, and more. It promotes international collaboration, encourages building intelligent structures, demonstrates the benefits of SHM methodologies for maintenance of structures, and advances the state-of-practice.

ISHMII is in a unique position to address the challenges facing the infrastructure of the 21st century where each system or structure, functioning as complimentary industries, is critical to economic development.

ISHMII is an international society with a truly global perspective. It is only through SHM that it will be possible to safely extend the service lives of the mature infrastructures of industrial nations or construct more daring futuristic larger span bridges, rail links and modern infrastructure systems in developing countries. That is why ISHMII needs you as highly respected expert to bring your competence and ideas to ISHMII.

As the President of ISHMII, I am pleased to welcome you, and look forward to working with you to accomplish our objectives and further this important work.

ITU

ITU is a reputable institution known for its history, science, technology, art and sport achievements over the period of 246 years. ITU, that has presented numerous scientific and technological developments, provides academic learning being one of the oldest and most prominent technical universities in the world.

With 23 engineering programs accredited by ABET Accreditation, ITU is the world's leader among universities. Students participating in International Exchange Graduate Programs complete a part of their education at one of the partner universities in the USA and receive a dual diploma.

ITU is the cradle of science, industry and technology conducting over 200 R&D projects in the scope of ARI Techno City. In cooperation with the entrepreneurship ecosystem ITU Seed, the university provides support to students-entrepreneurs.

Long history, intelligent minds and outstanding academic environment of ITU form a strong bridge connecting the past to the future. With the priority for continuous development, innovative perspective and strong international contacts ITU proves to be the university of the past, present and future.

Institutional Sponsors

RILEM

The mission of RILEM 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, industrialists, testing laboratories and authorities.

In 1956, the first RILEM Technical Committee was created, on the topic of 'Winter Concreting'. Since then almost 300 Technical Committees have been active, producing State-of-the-art reports and/or Test Recommendations.

RILEM has been organising symposia and workshops since its foundation. Through its subsidiary company RILEM Publications Sarl, RILEM has published more than 130 proceedings since 1997. A quick glance at http://www.rilem.net shows the diversity, the importance, and the international scope of the topics.

To broaden the education of both PhD students and the professional community, RILEM sponsors interesting and informative PhD courses and seminars on subjects of relevance to researchers working in specific areas.

RILEM has about 1500 individual members worldwide, and over 100 corporate members.

Sensors

Sensors (ISSN 1424-8220; CODEN: SENSC9; https://www.mdpi.com/journal/sensors) is a leading journal devoted to fast publication of the latest achievements of technological developments and scientific research in the huge area of physical, chemical and biochemical sensors, including remote sensing and sensor networks. Both experimental and theoretical papers are published, including all aspects of sensor design, technology, proof of concept and application. Sensors organises Special Issues devoted to specific sensing areas and application each year.

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materials

Materials

Materials (ISSN 1996-1944) was launched in 2008. The journal covers eighteen comprehensive topics: biomaterials, energy materials, advanced composites, structure analysis and characterization, porous materials, manufacturing processes and systems, advanced nanomaterials, smart materials, thin films, catalytic materials and carbon materials, materials chemistry, materials physics, optics and photonics, corrosion and materials degradation, construction and building materials, materials simulation and design, electronic materials, general. The distinguished and dedicated editorial board and our strict peer-review process ensure the highest degree of scientific rigor and review of all published articles. Materials provides a unique opportunity to contribute high quality articles and to take advantage of its large readership. We aim to encourage various scientific communities to publish their original experimental and theoretical research, as well as their reviews. Therefore, there is no restriction on the length of the papers. The full experimental details must be provided so that the results can be reproduced. We are also pleased to inform that Materials received an updated Journal Impact Factor of 2.972 in the recent release of the Journal Citation Reports®. The journal's 5-Year Impact Factor is 3.532. Materials now ranks 102/293 (Q2) in the category 'Materials Science, Multidisciplinary.'

Venue

Dorint Sanssouci Berlin-Potsdam

Jägerallee 20, 14469 Potsdam

The 4-star superior Dorint Hotel Sanssouci Potsdam is much more than a modern city hotel. It is the ideal starting point for your journey of discovery through the old and beautifully restored former royal seat of Potsdam. And it is the ideal location for hosting a seminar or conference here outside the gates of Berlin. Discover the beauty of Potsdam when you visit the impressive palace grounds of Sanssouci, undertake an excursion to the Wannsee Lake and Babelsberg Film Park, where Hollywood stars abound. The great author, Theodor Fontane, wrote his most famous works here in Potsdam.

Parking: underground garage with 200 parking spaces (entrance height 1.90 m), costs 20 € per 24 hours

DIRECTIONS BY PUBLIC TRANSPORT

By train

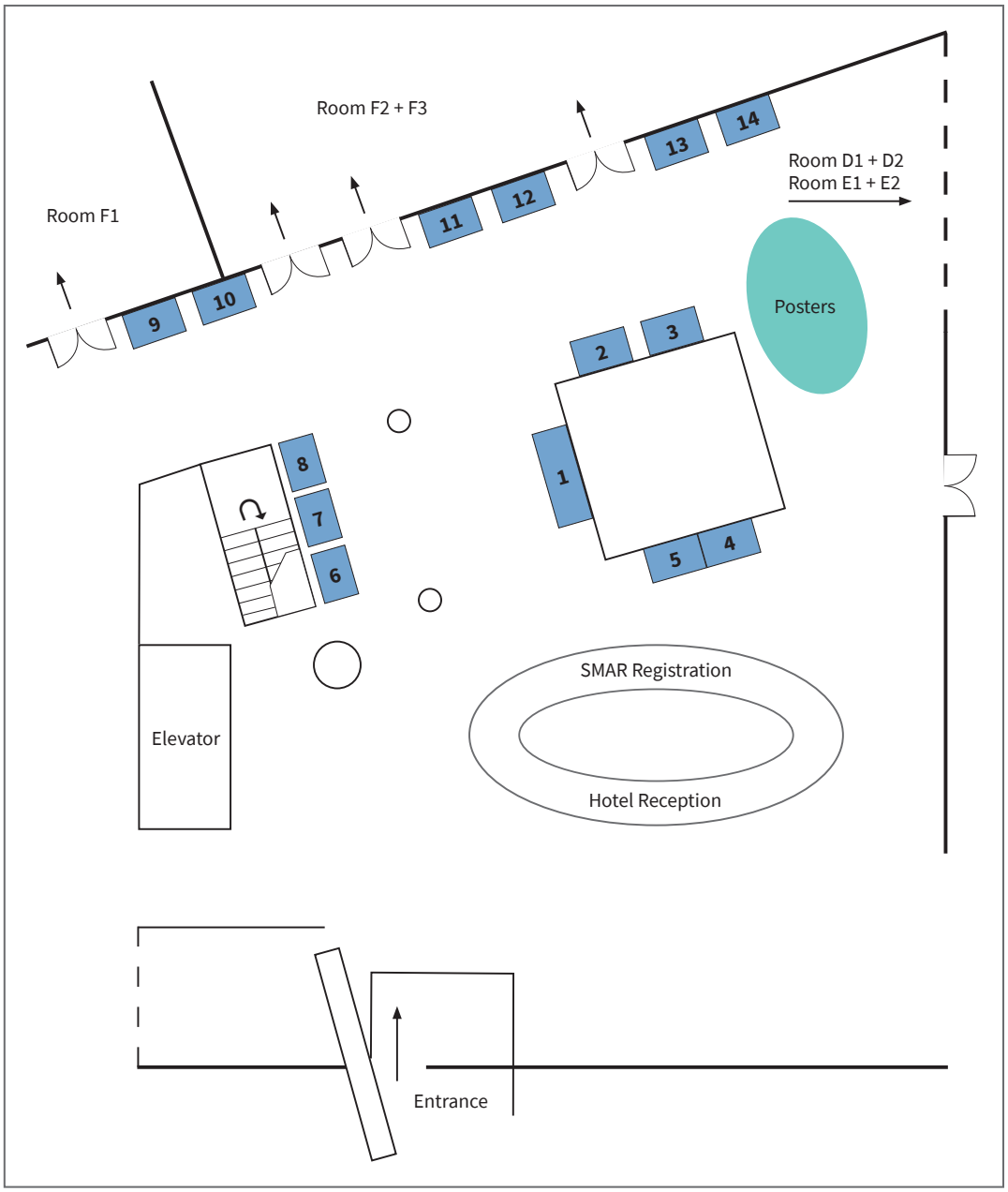
- from Berlin „Hauptbahnhof“ to Potsdam please take the S-Bahn S7 direction Potsdam Hauptbahnhof or the regional express train RE1
- from Potsdam Hauptbahnhof take the bus 695 to „Bahnhof Pirschheide” and exit at „Reiterweg/Jägerallee”

From airport

- airport Berlin Tegel (TXL), about 30 km: by bus 109 until station „Charlottenburg“, then change to S-Bahn S7 direction Potsdam Hauptbahnhof, then see above
- airport Berlin Schönefeld (SXF), about 39 km: different ways, for instance regional express train RE7 to station „S Ostkreuz“ and change to S-Bahn S7 direction Potsdam Hauptbahnhof, then see above

Directions of public transport system please find at www.bvg.de or www.swp-potsdam.de/de/verkehr.

Your name badge for the conference serves as ticket for the public transport system for Berlin and Potsdam (tariff area ABC) from 26 – 29 August 2019.



EXHIBITORS

1	Proceq AG
2	S & P Clever Reinforcement Company AG
3	BS2 Sicherheitssysteme GmbH
4-5	Polytec GmbH
6	re-fer AG
7	Kiwa GmbH
8	Lunitek SRL
9	TFB Diagnostic Systems AG
10	HBM – Hottinger Baldwin Messtechnik GmbH
11	ElastiSense
12	SECOPTA analytics GmbH
13	Strucinspect/Palfinger Structural Inspection GmbH
14	SHM System Sp. z o.o. Sp. kom.

Sponsors & Exhibitors

GOLD SPONSOR

Proceq AG

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Proceq (www.proceq.com) headquartered in Switzerland is shaping the future of screening and sensing technologies for a wide range of materials. The company utilizes latest technologies to digitize the non-destructive testing (NDT) industry with powerful portable and connected devices.

Proceq, part of the Tectus Group, has been providing innovative inspection and testing solutions since 1954 using a wide range of techniques. With strong R&D teams in Switzerland and Singapore, the firm continues to lead the industry in innovation and introduction of new solutions.

Proceq's high quality devices are Swiss Made, and with subsidiaries in Brazil, the United States of America, the United Kingdom, Russia, the United Arab Emirates, China, Singapore, and a network of over 200 sales and service partners, Proceq provides best in class customer support and service.

Proceq® GPR Live is a groundbreaking Ground Penetrating Radar (GPR) for the subsurface imaging of concrete structures. Powered by the world's first Stepped Frequency Continuous Wave (SFCW) hardware miniaturized in a handheld scanner and driven with cutting-edge algorithms, intuitive software on Apple iPad, and cloud computing, Proceq GPR allows real-time imaging that has been so far not thought possible.

Proceq GPR Live is also the world's first large scale Augmented Reality (AR)-empowered solution for industry application, available on iPad with iOS 12. You can now augment the world around you with GPR 2D and 3D visualizations that will merge seamlessly with the environment around you.

Pundit® Live Array Pro is a breakthrough in on-site productivity and image clarity for concrete NDT. This includes thick concrete elements, such as tunnel lining, as well as pipes and tendon ducts beyond the rebar layer – now in on-site 3D.

Simply connect the transducer to your iPad and easily measure concrete thickness, and detect defects and objects in structures. The rugged, compact, wireless transducer array incorporates cutting-edge multi-channel Ultrasonic Pulse Echo (UPE) technology. Together with a positioning system powered by Artificial Intelligence (AI), Pundit Live Array Pro delivers unmatched industry performance.

Screening Eagle®, developed by Tectus Dreamlab Pte Ltd., is a holistic cloud-based telematics platform for intelligent inspection and predictive maintenance of assets and infrastructure. It enables real time data sharing and data management for asset monitoring, maintenance and inspection of assets to secure data integrity over the entire lifecycle.

The Screening Eagle platform connects high-performance Internet of Things (IoT) sensors from robotics to traditional devices with workflow software and data visualization and analytics to deliver a full-stack solution that enhances the productivity, data integrity, safety of the assets while reducing total cost of ownership and boosting net present value.

Other renowned Proceq brands include Schmidt®, Profometer®, Zehntner®, Equotip® and Carboteq®.

SILVER SPONSOR

S & P Clever Reinforcement Company AG

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Country	Switzerland

S&P is one of the world-wide leading manufacturers of materials for the FRP strengthening of reinforced concrete structures and of reinforced bituminous pavements. Additionally, reinforcement systems to control soil erosion, for rock support and for dam construction are offered. S&P's Engineering Department provides assistance in the optimum selection from the comprehensive S&P product range.

The S&P reinforcement systems are manufactured from fibre roving made of different materials such as carbon, glass, aramid and polyester. S&P's own static design software is available to engineers as well as to planning and design offices. The S&P systems are exclusively applied by specialized applicators trained by S&P who guarantee a high quality application of the S&P reinforcement systems.

PRODUCT RANGE

Fibre reinforced polymer (FRP)

S&P laminates (FRP plates) are used for flexural enhancement. The product can be surface bonded or near surface mounted. A pre-stressed application is also possible. Additionally S&P is producing different unidirectional respectively bidirectional sheets out of carbon fibres, aramid fibres respectively glass fibres. The S&P sheets are used for seismic impact or axial enhancement of RC structures. S&P offers the dimensioning software FRP Lamella and FRP Colonna.

S&P ARMO-SYSTEM

In the S&P ARMO-System the S&P ARMO-mesh is used in combination with cementitious mortar. The system is previewed for static retrofitting of all kind of RC structures in tunnelling and general building. A combination of S&P ARMO-mesh with plaster (S&P ARMO-mur) is an option for seismic retrofitting of masonry walls. S&P offers the dimensioning software ARMO-flexion and ARMO-axial.

Pre-bituminised S&P asphalt grids

Two types are available:

- S&P Glasphalt is used against fatigue, thermal and reflective cracking in bituminous pavement.
- S&P Carbophalt is used exactly like S&P Glasphalt. In addition to that S&P Carbophalt will increase the stiffness of the pavement layer. Different researches have shown that the increase of stiffness thanks to S&P Carbophalt is similar like 3–4 cm additional pavement.

S&P GEOGRIDS FOR SOIL REINFORCEMENT

The S&P grids out of polyester are used for rock stabilization respectively erosion control of steep slopes. The grids are also used for all kind of reinforced soil. S&P offers the dimensioning software S&P Slope.

Exhibitors

BS2 Sicherheitssyteme GmbH

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Website	www.bs2-sicherheitssysteme.de
Country	Germany

Concrete plus steel, this combination is synonymous with simple processing, diversity of shapes, reasonable cost and high load acceptance within all areas of construction design.

The initially corrosion-proof reinforcement steel, due to material ageing and the influence of chemical substances, gradually loses its protective passivation layer. Unnoticed first from outside, corrosion sets in, which at a later stage can endanger the stability of the entire concrete structure. Once pitting, spalling and cracks are showing, the costs for repair are already on the higher side.

Our passive corrosion sensor provides a simple and cost effective solution for the protection of buildings: The sensor responds before the steel is damaged. The corrosion sensors are used in exposed areas before or after concreting, with the help of a core hole.

Our corrosion early-warning system provides reliable detection of the factors causing corrosion before the reinforcement steel gets affected and the warranty period has expired. Our „passive“ energy- and cableless System Corro-Dec®2G excells by its simple handling, combined with a high degree of safety and reliability. You can read the measured data conveniently on your mobile terminal. With this budget-friendly, cableless sensor device of high longevity and simple installation technique, both capital and follow-up costs can be kept at a reasonable level.

Our corrosion sensors can be installed without much effort both during concreting – e.g. during construction of new buildings or in the wake of renovation work, but can also be put in later on by core Drilling.

ElastiSense

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Country	Denmark

ElastiSense offer standard and customized sensor solutions for multiple industrial segments including Structural Health Monitoring (SHM).

Our mechanically flexible sensors are based on a ground-breaking sensor technology (ultra high-strain elastomer strain-gauge) which allows measurement of both linear and off-axis displacements.

The highly elastic characteristic makes the sensors inherently compatible to measuring structural movements such as crack propagation, deflection of supporting component, or bending or large metal parts.

Unlike piston-based sensors (LVDTs, Potentiometers, and Linear Encoders), ElastiSense sensors operates by being STRETCHED hence no sliding parts are present in its construction enhancing its simplicity and lifetime.

ElastiSense product portefolio includes standard sensor components as well as turnkey monitoring systems.

HBM – Hottinger Baldwin Messtechnik GmbH

Contact	Christina Barbosa
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Website	www.hbm.com
Country	Germany

For over 65 years, the name HBM has stood for reliability, precision and innovation all over the world. HBM Test and Measurement is the technology and market leader and offers products and services for an extensive range of measurement applications in many industries.

Users worldwide rely on the perfectly matched components of the complete measurement chain that guarantees maximum accuracy of measurement results and enables optimization of the complete product life cycle.

HBM‘s product range covers sensors, transducers, strain gauges, amplifiers and data acquisition systems as well as software for monitoring, structural durability, test and analysis. HBM FiberSensing, a business subsidiary of HBM Test and Measurement, focuses on the development and production of advanced monitoring systems based on optical Fiber Bragg Grating (FBG) technology.

HBM‘s potential fields of application can be found in every branch of engineering and industry in both virtual and physical test and measurement. HBM FiberSensing is specially requested for applications in markets such as Energy, Civil and Geotechnical Eng., Transportation, and Research, where optical solutions built with its own Sensors, Interrogators and Software can provide long-term, self-referenced and reliable measurements.

Kiwa GmbH

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Country	Germany

Kiwa – We create trust.

Kiwa is a leading specialist in the areas of testing, inspection and certification of building materials and building products. We are your partner for safety and quality for real estate and infrastructure, automotive and traffic as well as water and environment.

Exhibitors

Lunitek SRL

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Country	Italy

Lunitek designs and produces instruments for seismic and structural monitoring, providing also services and solutions for a wide range of applications including sesmology, civil engineering and oil&gas.

With 15 years experience in the field of instrumentation design for seismic and structural monitoring Lunitek operates in Italy and abroad and collaborates with universities and research centers.

Lunitek is ISO9001:2015 certified.

Polytec GmbH

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Country	Germany

Future since 1967! For Polytec, this means over 50 years of innovation, performance and quality measurement as supplier of optical measurement solutions. As technology leader for about 30 years in the field of laser Doppler vibrometry, Polytec has set the standards worldwide for non-contact vibration analysis. Besides vibrometry, Polytec develops and offers optical 3D surface metrology, laser-based speed and length sensors for production process control and process analytics. The company also focuses on distribution and service of optical sources, optical measurement instrumentation and machine vision components.

For decades, Polytec vibrometer systems have been established tools advancing the research and development of cutting edge products, driving innovative technologies and securing production quality in end-of-line testing by analyzing and visualizing the true dynamics of a sample structure. Laser vibration measurement is used for material testing, non-destructive testing, structural health monitoring, stress and strain distribution or experimental modal analysis, model validation, prototype testing and even in-line quality inspections. Whether for full-field analysis, remotely over larger distances, on microstructures or for 3D visualization, there is a Polytec laser vibrometer to provide the answer.

The ideal R&D process of FE model validation requires integration of the modal test into the CAE environment. Polytec offers complete solutions for modal analysis: Non-contact 3D scanning vibrometry with repeatable excitation by an automated modal hammer and the extraction of actual modal parameters allow this to happen. Software-based stitching offers a full 360° perspective of a sample. The detailed full-field understanding of the dynamics provides the right data for defining later quality inspections in the manufacturing line. Process-integrate, single-point industrial vibrometers enable reliable pass-fail-analysis based on the vibro-acoustic signature of produced parts.

In the field of distribution business, Polytec focuses on fiberoptical measurement systems for structural health monitoring, especially strain measurement and crack detection. The company offers a broad range of sensing instrumentation, based on different technologies to meet all kinds of applications. These optical systems enable a single optical fiber sensor with extremely high spatial resolution (1 mm) or sensor lengths of several kilometers.

re-fer AG

Contact	Julien Michels
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Country	Switzerland

re-fer is a provider of innovative solutions for structural strengthening of concrete and steel structures. We offer iron-based shape memory alloy (‚memory-steel') based products for prestressing applications. The end-anchored strips ‚re-plate' as well as the ribbed bars ‚re-bar' (in combination with grouts and sprayed mortar) represent an innovation in the construction sector regarding the technology and ease of application on site. Furthermore, we assist engineers and selected contractors in design and application questions.

SECOPTA analytics GmbH

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Country	Germany

We are supporting our customers worldwide with laser-based systems for analysing the chemical composition. With the concreteLIBS from Secopta analytics you have a Fast.Precise. and Robust. solution for research and development. The Laser-Induced Breakdown Spectroscopy is capable to provide crucial information for the monitoring of bridges, parking decks and other concrete infrastructure that are affected by deterioration.

Visit us at our booth and experience the enormous advantages of the LIBS technology for concrete analysis and discover how the visualization of the elements in concrete will advance you in research and development so you are always a step ahead.

No matter whether you need to:

- Unique selling point all-in-one LIBS system for fast 3-dimensional surface analysis of concrete in the laboratory
- Quantitative chloride analysis on concrete
- Precise determination of intrusion profiles in a millimeter scale to evaluate an accurate value for the residual service lifetime
- Recording of the essential elements for the characterization of building materials (Ca, Si, Fe, Al, Mg, O) and potentially damaging ions (Cl, S, Na, K).

We are looking forward to seeing you at our booth!

Exhibitors

SHM System Sp. z o.o. Sp. kom.

Contact	Tomasz Howiacki
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Country	Poland

SHM System are experts in providing measurement solutions for geotechnics and civil engineering. The team consists of scientists and engineers each with over 10 years of experience in the design and implementation of long-term structural health monitoring system.

SHM System provides measurement support for R&D departments of the largest construction companies in Europe – more than 100 measurement systems have been designed and implemented over the last 6 years. We support our partners at every stage of the project process, from the idea through design and installation to the analysis of measurement data. Thanks to its own research and development department, SHM System has launched and patented a number of world-class innovative measurement solutions, including the design and production technology of composite optical fibre sensors DFOS: EpsilonRebar and 3DSensor.

DFOS has changed the traditional way of understanding measurement – it has created the ability to observe the distribution of phenomena over the entire length of fibre, which can be thousands of meters long. The innovative construction of the sensors ensures the effectiveness of the strain transfer along the optical fibre, which is an integral part of the sensor. The unique shape ensures perfect cooperation between the sensor and the surrounding structure, and the specially developed composite guarantees the largest possible measuring range up to the strength limit of the glass measuring fibres.

Strucinspect/Palfinger Structural Inspection GmbH

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Country	Austria

Structural inspections can be carried out much more precisely, economically and sustainably in the future.

PALFINGER, VCE and the ANGST GROUP have so far approached this topic from independent directions. Now these companies have joined forces to co-operate and combine their experience in providing a unique and revolutionary solution for the market – the digitization of structural assessment.

STRUCINSPECT covers the entire process chain of structural inspection: from complete acquisition and digitization of the structure, to objectified structural analysis and condition assessment. With high-resolution cameras and sensors, thousands of images of the inspection subject are taken. From this data, a digital twin – an exact 3D model of the real structure – is produced. This virtual representation depicts the overall general condition, as well as all specific damage and material condition. Using this method, spallings and cracks can be precisely identified and examined with a resolution of up to 0.1 mm. Any detected damage is recorded in a database as well as clearly displayed on the digital model. The damage detection is done using neural networks where, all damage is identified, analyzed, marked and documented. The software also differentiates between a wide variety of damage types and intensities. The quality of the result is thus no longer dependent on individual subjective opinion. The achieved objective data evaluation and interpretation forms the basis for a timely and rapid assessment by experts.

STRUCINSPECT is less time-consuming compared to conventional structural inspections and provides a detailed snapshot as well as a fully holistic impression of the current state to clients, examiners and authorities. The data collection approach (e.g. using drones) and location-independent subsequent data analysis minimizes any traffic disturbance.

TFB Diagnostic Systems AG

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Country	Switzerland

TFB Diagnostic Systems AG develops, produces and sells systems for testing and monitoring building materials and structures. For its systems, TFB DS provides cloud services for data acquisition, data processing, visualisation and evaluation.

TFB Diagnostic Systems AG is specialised on monitoring corrosion and additional durability parameters of concrete structures. Our products include sensors and measuring technique (data logger) with the newest communication technology for data transfer (LoRaWAN) as well as innovative devices for Swiss durability testing on concrete in accordance with SN EN 206.

Tuesday, 27 August 2019

	Room F2 + F3	Room F1
09:00	Opening	
10:15 – 11:25	**Tu.1.A**	
	Keynote Presentations | *R. Helmerich, M. Motavalli*	
11:25	Welcome address presented by gold sponsor Proceq followed by welcome address presented by ISHMI	
13:00 – 15:00	**Tu.2.A**	**Tu.2.B**
	SHM between Research and Application: New Concepts for New Technologies | *Y. Petryna, S. Cho*	**Shape Memory Alloys (SMAs) for Engineering Applications (I)** | *M. Shahverdi, C. Czaderski*
15:30 – 17:00	**Tu.3.A**	**Tu.3.B**
	Shape Memory Alloys (SMAs) for Engineering Applications (II) | *M. Shahverdi, S. Saiidi*	**Damage Control, Repair and Strengthening (II)** *A. Ilki, S. Moy*
18:30 *(Bus transfer 17:15 h)*	Welcome reception *and laboratory visits at BAM*	

Wednesday, 28 August 2019

	Room F2 + F3	Room F1
08:30 – 09:50	**We.1.A**	
	Keynote Presentations | *R. Helmerich, M. Motavalli*	
09:50	Welcome address presented by IIFC	
10:30 – 12:30	**We.2.A**	**We.2.B**
	Shape Memory Alloys (SMAs) for Engineering Applications (III) | *M. Shahverdi, A. Cladera, E. Choi*	**Damage Control, Repair and Strengthening (III)** *A. Ilki, M. Breveglieri*
14:00 – 16:00	**We.3.A**	**We.3.B**
	Strengthening, Monitoring and Life-cycle Assessment of Metallic Structures (I) | *E. Ghafoori, R. Helmerich*	**Damage Control, Repair and Strengthening (IV)** *E. Ferrier, G.P. Lignola*
16:30 – 18:15	**We.4.A**	**We.4.B**
	Durability and Corrosion Monitoring of Concrete Infrastructures | *U. Angst, S. Keßler*	**Durability Issues as related to Harsh Environments – Fire Protection Systems** | *P. Sarker, J. Myers*
19:00	Conference Dinner at Biosphäre Potsdam	

Thursday, 29 August 2019

	Room F2 + F3	Room F1
08:30 – 09:50	**Th.1.A**	
	Keynote Presentations | *A. Ilki*	
10:20 – 12:05	**Th.2.A**	**Th.2.B**
	Testing, Inspection, Monitoring and Repair of Offshore Wind Energy Converters *M. Baeßler, R. Schneider*	**Laboratory Test of the Effectivity of External non FRP Strengthening Layers** | *G. Ferrara, B. Chen*
13:30 – 15:30	**Th.3.A**	**Th.3.B**
	Visionary Concepts, Deep Learning | *J. Myers, S. Cho*	**Strengthening, Monitoring and Life-cycle Assessment of Metallic Structures (II)** | *E. Ghafoori, Q.-Q. Yu*
15:45	Closing and Awards, Announcement of next SMAR Conference	

	Room E1 + E2	Room D1 + D2
13:00 – 15:00	**Tu.2.C** **Damage Control, Repair and Strengthening (I)** *J. Barros, E. Martinelli*	**Tu.2.D** **Non-Destructive Testing in Civil Engineering (I)** *E. Niederleithinger, Q.-Q. Yu*
15:30 – 17:00	**Tu.3.C** **SHM – Smart Sensors (I)** *M. Motavalli, W. Lienhart*	**Tu.3.D** **Performance and Damage Assessment – Safety Evaluation and Reliability Forecast** *J. Gao, A. Miyamoto*
10:30 – 12:30	**We.2.C** **SHM – Smart Sensors (II)** *M. Bartholmai, C. Mertz*	**We.2.D** **Non-Destructive Testing in Civil Engineering (II)** *M.K. Rahman, J. Myers*
14:00 – 16:00	**We.3.C** **Performance and Damage Assessment** *J. Shah, J. Myers*	
16:30 – 18:15	**We.4.C** **Dynamic Vibration-based Monitoring, Seismic Performance** | *M. Motavalli, E. Martinelli*	**We.4.D** **Practical Applications and Case Studies (I)** *A. Ilki, M. Hueppi*
10:20 – 12:05	**Th.2.C** **SHM – Structural Health Monitoring on Bridges, Advanced Inspection and Testing** *A. Miyamoto, W. Lienhart*	**Th.2.D** **Practical Applications and Case Studies (II)** *J. Barros, E. Brühwiler*
13:30 – 15:30	**Th.3.C** **SHM – System Identification and Model Updating** *E. Brühwiler, A. Miyamoto*	

Keynote Speakers

Joaquim António Oliveira de Barros
Professor of the Department of Civil Engineering of Minho University, Italy

Keynote lecture:
Extending the Strengthening Potentialties of Near Surface Mounted Technique: From Experimental Evidence to Advanced Numerical Simulations

Joaquim A. O. Barros is Full Professor of the Department of Civil Engineering of Minho University and coordinator of the Structural Composites Group. He is a Fellow American Concrete Institute (ACI), and member of ACI (440 and 544) and fib (4.1, 4.3 and 5.1) Technical Committees, and Convener of the fib TG 2.4.2 Modelling of Fibre Reinforced Concrete Structures. He was member of RILEM (TC 162-TDF and TC-234-DUC), council member of the International Institute for FRP in Construction (IIFC), and member of the Scientific Advisory Committee of the Australian "Design Guideline for RC structures retrofitted with FRP and metal plates: beams and slabs". His research interests include structural strengthening, composite materials, fiber reinforced concrete and the development of constitutive models for the simulation of the behavior of cement based and polymer based materials, and their implementation in software based on the finite element method (FEM). He his author of more than 650 papers divided by books, chapter of books, journal papers (>175 in ISI journals), conferences, monographs and educational reports. Chairman of 8 international conferences, 4 national conferences, and 7 Seminars/Workshops. He is the co-founder of FEMIX, a FEM-based computer program for advanced structural analysis. He participates(ed) in 37 research projects (23 as coordinator). Supervisor of 7 Pos-Doc (concluded), 41 PhD (31 concluded) and 33 MSc (32 concluded). He is the founder of the CiviTest Company (www.civitest.pt), and consultant on the areas of fiber reinforced concrete (FRC) structures, structural rehabilitation and strengthening, and for the development of new materials for innovative structures. He is a co-inventor of several national and international patents.

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Eugen Brühwiler
Professor and Director of the Laboratory for Maintenance and Safety of structures, School of Architecture, Civil and Environmental Engineering (ENAC), Swiss Federal Institute of Technology in Lausanne (EPFL), Switzerland

Keynote lecture:
Adding value to bridges by monitoring and UHPFRC technology

Eugen Brühwiler is a Professor of structural engineering at EPFL since 1995 and leads the Laboratory of Maintenance, Construction and Safety of Structures (MCS). The mission includes the development of examination methods for existing structures ("Examineering") like bridges and buildings with the ultimate goal of limiting construction intervention to a strict minimum. If interventions are necessary, their objective must be to improve the structure, often using novel intervention technologies. This goal is in agreement with the principles of sustainable development.

Novel examination methods include the explicit implementation of data from structural monitoring, complemented by structural analysis, to verify sufficient fatigue and structural safety of steel and reinforced concrete bridges. Novel intervention technologies include the use of Ultra-High Performance Fiber Reinforced Cementitious Composites (UHPFRC) for the rehabilitation and strengthening of structures, in particular concrete bridges. Research findings are implemented in numerous applications to enhance existing bridges and buildings. In addition, E.B. significantly contributed to the elaboration of the Swiss Standard SIA269 for the engineering of existing structures. As an expert for the cultural heritage authorities of the Swiss Government, he is involved in the examination and restoration of structures of high cultural value, in particular riveted steel bridges, early reinforced concrete and natural stone masonry structures.

Baochun Chen
Professor of Bridge Engineering, College of Civil Engineering, Fuzhou University, China

Keynote lecture:

Damage control, repair and strengthening of concrete arch bridges in China

Professor Chen received a B.Sc. of Highway and Bridge Engineering from Fuzhou University, China, in 1982. After working as a bridge engineer in a construction company about two years, he returned back to Fuzhou University to continue his postgraduate study and received his M.S. of Structural Engineering in 1985. After graduation he has been working as a teacher in Fuzhou University. He received his Ph.D. of Structural Enginering in Kyushu University, Japan, in 2003. He became a professor in 2000 and had served as the vice dean of the College of Civil Engineering, Fuzhou University from 1997 to 2003 and the dean from 2004 to 2015.

Professor Chen teaches and leads research in the field of bridge engineering. His primary research areas involve the experimental investigation, design theory and application of innovative technology on arch bridges, jointless bridges, ultra-high performance concrete bridges, etc. In particular, he focuses his researches on the design theory of Concrete-filled Steel Tube (CFST) arch bridges through experimental study, finite element analyses and theoretical researches as well as real engineering practice more than 20 years, published five books on its theory and application, as chief editor edited the China national specification on CFST arch bridges. CFST arch bridges exploit the features of composite materials and arch structures, and more than 400 such type bridges have been built in China with a longest span of 530m. Professor Chen's interests include also the safety, damage control, rehabilitation and strengthening of concrete arch bridges, CFST arch bridges, stone arch bridges and so on.

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Danièle Waldmann-Diederich
Associate Professor of Structural Engineering in Solid Structures, Head of the Research Group for Solid Structures, Head of Institute for Civil and Environmental Engineering INCEEN, University of Luxembourg

Keynote lecture:

Potential of the Deformation Area Difference (DAD)-Method for Condition Assessment of Bridge Structures

Danièle Waldmann-Diederich joined the University of Luxembourg (https://wwwen.uni.lu) in 2003 as associate professor. She established the "Solid Structures (LSS)" research group, which puts its focus on (1) Structural Health Monitoring, (2) Reliable structural analysis of reinforced or prestressed concrete structures, (3) Inventive concrete formulations by material substitutions using waste or renewable products and (4) Advanced computational modelling for concrete using Multi-Physics Numerical Simulation (since 2018). She currently leads a research group of two Postdocs and six PhD students. To date, she published over 40 scientific journal papers and 70 conference papers. The research group is recognized for (a) Structural Health Monitoring to identify and localize damage on bridge structures by the development of the new Deformation Area Difference Method (DAD-Method) and by using most modern measurement techniques such as photogrammetry combined to drones; (b) developing a new design method for steel fiber-reinforced flat slabs taking into account the real orientation factor for large elements and (c) demountable dry-stacked modular masonry blocks. Having worked in industry and thus benefiting from excellent industrial background, she rapidly consolidated the group's national and cross-border contacts with world-leading industry, regional stakeholders and national administration to efficiently initiate competitive research guaranteeing a straightforward knowledge and technology transfer towards the industry.

Keynote Speakers

Janet Lees
Professor of Civil Engineering, Department of Engineering
University of Cambridge, UK

Keynote lecture:

Mismatches between design and condition assessment in reinforced concrete with or without FRP strengthening

Dr Janet Lees is a Professor of Civil Engineering at the University of Cambridge and a Fellow of the Institution of Civil Engineers. She is the Head of the Structures Research Group within the Civil Engineering Division at Cambridge and leads the Concrete Infrastructure Research Group. The main interests of her research group relate to the development of more sustainable reinforced concrete infrastructure. Ongoing project areas include the strength assessment of existing infrastructure, tailored reinforced concrete infrastructure and the use of high performance materials in construction. She is a Director of Cambridge's EPSRC Centre for Doctoral Training (CDT) in Future Infrastructure and Built Environment (FIBE) and EPSRC CDT in Future Infrastructure and Built Environment: Resilience in a Changing World (FIBE2). She was awarded an EPSRC Established Career Fellowship in 2017.

Ahmet Yakut
Professor at Structural Engineering Laboratory,
Department of Civil Engineering, Middle East Technical
University, Ankara, Turkey

Keynote lecture:

Recent Advances on Assessment of Seismic Performance of Existing Structures

Ahmet Yakut is a Professor of Structural Engineering and Director of Earthquake Engineering Research Center at Middle East Technical University. He received his BS and MS degrees from Middle East Technical University in 1989 and 1992, respectively. He studied at The University of Texas at Austin for his PhD during 1996-2000. He worked as a senior research engineering at Applied Insurance Research in Boston from 2000-2002 where he worked on development of earthquake insurance models. He has been a faculty member at the department of Civil Engineering of Middle East Technical University since 2002. His main areas of research cover Earthquake Engineering, Seismic Performance and Vulnerability Assessment of Buildings, Seismic Risk Analysis and Structural Analysis. He has taken part in the development of recent seismic codes in Turkey; Provisions to identify high risk buildings in Turkey (2013, 2019) and Turkish Building Earthquake Code (2019). He is a member of several National and International organisations. He has directed some national and international projects (EU projects) related to seismic performance and vulnerability analysis of buildings. He worked as national team leader in LESSLOSS project and was co-national coordinator in SYNER-G. He has also coordinated the METU contribution to INSYSME project. He has nearly forty papers published in the international journals in the field of structural and earthquake engineering.

Programme

	Room F2 + F3	Room F1
09:00	**OPENING**	
10:00	Break	
	Tu.1.A	
▶	**KEYNOTE PRESENTATIONS** *R. Helmerich, M. Motavalli*	
10:15	**Tu.1.A.1**	
	Adding value to bridges by monitoring and UHPFRC technology *E. Brühwiler [1]* *[1] Swiss Federal Institute of Technology EPFL, Lausanne, Switzerland*	
10:50	**Tu.1.A.2**	
	Potential of the Deformation Area Difference (DAD)-Method for Condition Assessment of Bridge Structures *D. Waldmann-Diederich [1], D. Erdenebat [1]* *[1] University of Luxembourg, Esch-sur-Alzette, Luxembourg*	
11:25	**WELCOME ADDRESSES** presented by gold sponsor Proceq followed by welcome address presented by ISHMII	
11:45	Lunch	
	Tu.2.A	**Tu.2.B**
▶	**SHM BETWEEN RESEARCH AND APPLICATION: NEW CONCEPTS FOR NEW TECHNOLOGIES** *Y. Petryna, S. Cho*	**SHAPE MEMORY ALLOYS (SMAS) FOR ENGINEERING APPLICATIONS (I)** *M. Shahverdi, C. Czaderski*
13:00	**Tu.2.A.1**	**Tu.2.B.1**
	Structural health monitoring of the Kurpsai dam in the Kyrgyz Republic *M. Pilz [1], K. Fleming [1], T. Boxberger [1], S. Orunbaev [2]* *[1] GFZ – German Research Center for Geosciences, Potsdam, Germany; [2] Central Asian Institute for Applied Geosciences, Bishkek, Kyrgyzstan*	An overview of research on SMAs with a focus on seismic risk mitigation *H.H. Aydoğdu [1], A. Ilki [1]* *[1] Istanbul Technical University, Istanbul, Turkey*
13:15	**Tu.2.A.2**	**Tu.2.B.2**
	Satellite Based Longterm Deformation Monitoring on Dams and its Surroundings *O. Lang [1], D. Walter [1], J. Anderssohn [1]* *[1] Airbus Defence and Space, Potsdam, Germany*	STRUCTURAL CONCRETE STRENGTHENING with Fe-SMA STRIPS: CASE STUDY with specific CONTROL AFTER ACTIVATION *J. Mercier [1], B. Basile [1], X. Hallopeau [1], J. Michels [2], C. Tourneur [1]* *[1] FREYSSINET International & Cie Département Technique, Rueil-Malmaison, France; [2] Re-fer AG, Brunnen, Switzerland*
13:30	**Tu.2.A.3**	**Tu.2.B.3**
	Structural Health Monitoring (SHM) of transport infrastructure – challenges, solutions, trends *J. Kuehne [1]* *[1] Wölfel Engineering GmbH + Co. KG, Höchberg, Germany*	Effectiveness of NiTi-SMA Bars at the Beam Column Joint Interface *M. Rahman [1], M. Al-Huri [1], A. Al-Gadhib [1], M. Baluch [1], M. Alosta [1]* *[1] King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia*
13:45	**Tu.2.A.4**	**Tu.2.B.4**
	Safety equivalent assessment of bridges considering structural monitoring *N. Steffens [1], K. Geißler [1]* *[1] TU Berlin, Germany*	Behavior of iron-based shape memory alloys under cyclic loading histories *D. Isidoro Heredia Rosa [1], A. Hartloper [1], A. Sousa [1], D. Lignos [1], M. Motavalli [2], E. Ghafoori [2]* *[1] Ecole Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland; [2] Empa, Dübendorf, Switzerland*

Tu.2.C

DAMAGE CONTROL, REPAIR AND STRENGTHENING (I)

J. Barros, E. Martinelli

13:00 **Tu.2.C.1**

Bond performance at elevated temperatures of near surface mounted CFRP laminates using cement-based adhesives

R. Mohammadi Firouz[1], E. Pereira[1], J. Barros[1]
[1] Institute for Sustainability and Innovation in Structural Engineering (ISISE), Guimarães, Portugal

13:15 **Tu.2.C.2**

Innovative nanostructured materials as cold-cured adhesive/matrix of FRP for strengthening of building structures

M. Frigione[1], M. Lettieri[2], F. Lionetto[1], L. Mascia[3]
[1] University of Salento, Lecce, Italy; [2] CNR – IBAM, Lecce, Italy; [3] Loughborough University, Loughborough, United Kingdom

13:30 **Tu.2.C.3**

Lifetime prediction of flax fibre reinforced composites

R. Chlela[1], M. Quiertant[1], W. Zombré[2], L. Curtil[2], D. Bigaud[3], K. Benzarti[1]
[1] IFSTTAR, Marne-la-Vallée Cedex 2, France; [2] LMC2, Lyon, France; [3] LARIS, Angers, France

13:45 **Tu.2.C.4**

Influence of UHPC laminate application type on fracture behavior of reinforced concrete beams strengthened in flexure

S. Tayfur[1], N. Alver[1], H.M. Tanarslan[2], R. Jahangiri[2]
[1] Ege University, Izmir, Turkey; [2] Dokuz Eylul University, Izmir, Turkey

Tu.2.D

NON-DESTRUCTIVE TESTING IN CIVIL ENGINEERING (I)

E. Niederleithinger, Q.-Q. Yu

Tu.2.D.1

Review of recent developments in ultrasonic echo testing of concrete

E. Niederleithinger[1], S. Maack[1], F. Mielentz[1], U. Effner[1], C. Strangfeld[1]
[1] BAM, Berlin, Germany

Tu.2.D.2

Characterization of Moisture Transport Properties of Cement-based Materials using Electrical Capacitance Tomography

A. Voss[1], M. Pour-Ghaz[2], M. Vauhkonen[1], A. Seppänen[1]
[1] University of Eastern Finland, Kuopio, Finland; [2] North Carolina State University, Raleigh, USA

Tu.2.D.3

Comprehensive Full-Depth Evaluation of Concrete Bridge Decks Based on GPR Surveys and Machine Learning

A. Imani[1], S. Saadati[1], N. Gucunski[1]
[1] Rutgers University, Piscataway, USA

Tu.2.D.4

Towards predictor development for assessing structural integrity of components made from wood materials using Acoustic Emission monitoring and signal analysis

F. Baensch[1], A.J. Brunner[2]
[1] BAM, Berlin, Germany; [2] Empa, Dübendorf, Switzerland

	Room F2 + F3	Room F1
14:00	**Tu.2.A.5** Long-term SHM system for a concrete gravity dam *Y. Petryna [1], P. Kähler [1], W. Elsesser [1]* *[1] TU Berlin, Germany*	**Tu.2.B.5** Shear strengthening using external Fe-SMA strips *L.A. Montoya-Coronado [1], J.G. Ruiz-Pinilla [1], C. Ribas [1], A. Cladera [1]* *[1] University of Balearic Islands, Palma (Balearic Islands), Spain*
14:15	**Tu.2.A.6** Local and global state parameter extraction from ambient vibration measurements on bridges *P. Kähler [1], Y. Petryna [1]* *[1] TU Berlin, Germany*	**Tu.2.B.6** 3-D Non Linear Finite Element Modeling of Exterior R.C Beam-Column Joint Partially Reinforced With Shape Memory Alloys (SMAs) and Existing of Transverse Beam *A. Halahla [1], Y. Abu Tahnat [2]* *[1] Fahad Bin Sultan University, Tabuk, Saudi Arabia; [2] Middle East Technical University, Ankara, Turkey*
14:30	**Tu.2.A.7** Seismic screening approaches for detection of structural changes *C.-M. Liao [1], Y. Petryna [1]* *[1] TU Berlin, Germany*	**Tu.2.B.7** Long-term behavior of reinforced concrete beams strengthened by iron-based shape memory alloy strips *M. Shahverdi [1,2], C. Czaderski [1]* *[1] Empa, Dübendorf, Switzerland; [2] University of Tehran, Iran*
14:45	**Tu.2.A.8** Bridge Remote Sensing Using TerraSAR-X Satellite *E. Hoppe [1], F. Novali [2], A. Rucci [2], A. Fumagalli [2], S. Del Conte [3], G. Falorni [3], N. Toro [3]* *[1] Virginia Department of Transportation, Charlottesville, USA; [2] TRE ALTAMIRA s.r.l, Milano, Italy; [3] TRE ALTAMIRA Inc., Vancouver, Canada*	**Tu.2.B.8** Fire Behavior of Prestressed Iron-Based Shape Memory Alloy (Fe-SMA) *E. Ghafoori [1], M. Neuenschwander [2], M. Shahverdi [1], C. Czaderski [1], M. Fontana [3]* *[1] Empa, Dübendorf, Switzerland; [2] University of California Berkeley, Pacific Earthquake Engineering Research Center, Berkeley, USA; [3] ETH Zurich, Switzerland*
15:00	Break	
▶	**Tu.3.A** **SHAPE MEMORY ALLOYS (SMAS) FOR ENGINEERING APPLICATIONS (II)** *M. Shahverdi, S. Saiidi*	**Tu.3.B** **DAMAGE CONTROL, REPAIR AND STRENGTHENING (II)** *A. Ilki, S. Moy*
15:30	**Tu.3.A.1** (20 min) PLENARY LECTURE: Feasibility of Superelastic Large Diameter Copper-Aluminum-Manganese SMA Bars in Bridge Columns *S. Saiidi [1]* *[1] University of Nevada, Reno, Civil Engineering, Reno, USA*	**Tu.3.B.1** Bond resistance of prestressed CFRP strips to concrete substrate: comparative evaluation of EBR and EBROG methods *N. Moshiri [1,2], C. Czaderski [2], D. Mostofinejad [1], M. Motavalli [2]* *[1] Isfahan University of Technology, Isfahan, Iran; [2] Empa, Dübendorf, Switzerland*
15:45	**Tu.3.A.2** (10 min) Nailed iron-based shape memory alloy (Fe-SMA) strips for strengthening of steel members *E. Fritsch [1,2], M. Izadi [2,3], E. Ghafoori [2]* *[1] University of Natural Resources and Life Sciences, Vienna, Austria; [2] Empa, Dübendorf, Switzerland; [3] University of Tehran, Iran*	**Tu.3.B.2** EBROG technique to enhance the bond performance of CFRP strips to concrete substrate *C. Czaderski [1], N. Moshiri [2], A. Hosseini [1], D. Mostofinejad [2], M. Motavalli [1]* *[1] Empa, Dübendorf, Switzerland; [2] Isfahan University of Technology (IUT), Isfahan, Iran*
16:00	**Tu.3.A.3** Strengthening of concrete structures with iron-based shape memory alloy elements: Case studies *B. Schranz [1,2], J. Michels [1,3], M. Shahverdi [1,4], C. Czaderski [1]* *[1] Empa, Dübendorf, Switzerland; [2] ETH Zürich, Switzerland; [3] re-fer AG, Brunnen, Switzerland; [4] University of Tehran, Iran*	**Tu.3.B.3** Test study for full-scale hollow slab girder using UHPFRC reinforcement technology *L. Duan [1], C. Wang [1], S. Wang [1], Q. Wang [1], P. Zhang [1]* *[1] Chang'an University, Xi'an, China*

14:00 **Tu.2.C.5**

Fatigue Performance of FRCM Strengthened RC Beams Subjected to Varied Fatigue Frequencies and Environmental Exposure

Z. Aljazaeri [1], J. Myers [2]
[1] Nahrain University, Baghdad, USA; [2] Missouri University of Science and Technology, Rolla, Missouri, USA

Tu.2.D.5

Machine learning based multi-sensor fusion for the non-destructive testing of corrosion in concrete

T.N. Haller [1], C. Völker [2], T. Hartmann [1]
[1] TU Berlin, Germany; [2] BAM, Berlin, Germany

14:15 **Tu.2.D.6**

Super-resolution images for measuring structural response

R. Kromanis [1], C. Forbes [1], S. Borah [1]
[1] Nottingham Trent University, Nottingham, United Kingdom

14:30 **Tu.2.D.7**

Acoustic emission and ultrasonic testing for fatigue damage detection in a RC bridge deck slab

I. Bayane [1], E. Brühwiler [1]
[1] Ecole Polytechnique Fédérale de Lausanne, Switzerland

14:45 **Tu.2.D.8**

The Impact-Echo method applied to the auscultation of bridges: Numerical study

H. Rezgui Chaabounui [1], S. Yotte [1], M. Takarli [1]
[1] GC2D laboratory, Egletons, France

Tu.3.C

SHM – SMART SENSORS (I)

M. Motavalli, W. Lienhart

Tu.3.D

PERFORMANCE AND DAMAGE ASSESSMENT – SAFETY EVALUATION AND RELIABILITY FORECAST

J. Gao, A. Miyamoto

15:30 **Tu.3.C.1**

Integrated Optics Inclinometers for SHM

D. Inaudi [1], R. Blin [1], B. Timotijevic [2], D. Zaman Bayat [2], Y. Petremand [2], M. Luetzelschwab [2], N. Niketic [2]
[1] SMARTEC SA, Manno, Switzerland; [2] CSEM, Neuchâtel, Switzerland

Tu.3.D.1

Structural evaluation of a reactor building during pressure leak-rate testing for life extension assessment

M. Ceballos [1,2], C. Estrada [1], F. Pinto [1,2], M. Pomerantz [3], C. Prato [1]
[1] Universidad Nacional de Córdoba, Argentina; [2] Nucleoeléctrica Argentina (NA-SA), Córdoba, Argentina; [3] Consejo Nacional de Investigaciones Científicas y Técnicas, Argentina

15:45 **Tu.3.C.2**

Surface-applied distributed fiber-optic monitoring for crack detection in concrete structures: Technology overview and application challenges

N. Nöther [1], A. Künzel [2], F. Vogdt [2]
[1] fibrisTerre Systems GmbH, Berlin, Germany; [2] SENSICAL GmbH, Berlin, Germany

Tu.3.D.2

A Proposed Approach for Processing and Analyzing Strain Data Collected In Full-Scale Accelerated Pavement Testing

A. Francois [1], A. Ali [1], Y. Mehta [1]
[1] CREATEs at Rowan University, Glassboro, NJ, USA

16:00 **Tu.3.C.3**

Fibre-optic sensors in practical applications: challenges and technical needs for a successful use

W. Habel [1]
[1] formerly BAM, Berlin, Germany

Tu.3.D.3

A practical approach for modeling tendon and wire failures for model-based damage detection of prestressed concrete bridges

A. Seiffert [1], A. Jansen [2]
[1] Bundesanstalt für Straßenwesen, Bergisch Gladbach, Germany; [2] TU Berlin, Germany

	Room F2 + F3	Room F1
16:15	**Tu.3.A.4** 'memory steel' for Shear Reinforcement of Concrete Structures *M. Shahverdi [1], C. Czaderski [1], J. Michels [1,2]* *[1] Empa, Dübendorf, Switzerland; re-fer AG, Brunnen, Switzerland*	**Tu.3.B.4** Strengthening Glued Laminated Non-circular Timber Columns With CFRP Jacketing *O.A. Sisman [1], A. Isikara [1], A. Ilki [1]* *[1] ITU, Istanbul, Turkey*
16:30	**Tu.3.A.5** Damping devices using single & dual SMA rings *E. Choi [1], Y. Ha [1], D.H. Nguyen [1], H.T. Nguyen [1], T.Y. Kim [1], S.J. Park [1], Y.-S. Lee [1]* *[1] Hongik University, Seoul, South Korea*	**Tu.3.B.5** Experimental program on large-scale reinforced concrete columns strengthened with carbon FRP jackets *A. de Diego [1], S. Martínez [1], L. Echevarría [1], V.J. Castro [1], J.P. Gutiérrez [1]* *[1] IETCC, CSIC. Eduardo Torroja Institute for Construction Science, Madrid, Spain*
16:45	**Tu.3.A.6** Potentials and challenges for Fe-Mn-Al-Ni-X iron based shape memory alloys in civil engineering *M. Vollmer [1], C. Lauhoff [1], P. Krooß [1], A. Weidner [2], U. Prahl [2], H. Biermann [2], T. Niendorf [1]* *[1] University of Kassel, Germany; [2] Freiberg University of Mining and Technology, Freiberg, Germany*	**Tu.3.B.6** Influence of multiple anchors´ arrangement in the behaviour of FRP-to-concrete anchored joints *A. Cortez Flores [1], J. Fernández Gómez [1], P. Villanueva Llauradó [1]* *[1] Universidad Politécnica de Madrid, Spain*
18:30	Welcome reception and laboratory visits at BAM **Bus transfer 17:15 h**	

16:15 **Tu.3.C.4**

Self-Sensing Carbon Nanotube Reinforced Composites for Smart Cities

S.-H. Jang [1]

[1] Department of Civil and Coastal Engineering, University of Plymouth, United Kingdom

16:30 **Tu.3.C.5**

A hybrid optical fiber/wireless monitoring system for permeable pavements

J.-N. Wang [1], W.-T. Wu [2], C.-H. Chen [2], P.-K. Wu [1], J.-F. Wang [1]

[1] National Yunlin University of Science and Technology, Douliou, Taiwan (Republic of China); [2] National Pingtung University of Science and Technology, Pingtung, Taiwan (Republic of China)

16:45 **Tu.3.C.6**

A Coupled Damage-Plasticity Traction-Separation Law for Masonry

Y.P. Yuen [1], T. Deb [1], K.-M. Wang [1], Y.-C. Chen [1], C.-A. Tsai [1], W.-W. Chen [1]

[1] National Chiao Tung University, Hsinchu, Taiwan (Republic of China)

Tu.3.D.4

Possibilities to Enhance Tomography Imaging of Concrete Structures by the Full Waveform Inversion

T. Lahmer [1], M. Schickert [1], I. Reichert [2]

[1] Materialforschungs- und -Prüfanstalt, Weimar, Germany; [2] Bauhaus Universität Weimar, Germany

Tu.3.D.5

Application of Gaussian process metamodel in structural finite element model updating applying dynamic measured data

H. Moravej [1], T. Chan [1], K.-D. Nguyen [1], A. Jesus [2]

[1] Queensland University of Technology, Brisbane, Australia; [2] University of West London, London, United Kingdom

Room F2 + F3

We.1.A

KEYNOTE PRESENTATIONS

R. Helmerich, M. Motavalli

08:30 We.1.A.1

Mismatches between design and condition assessment in reinforced concrete with or without FRP strengthening

J. Lees [1]
[1] University of Cambridge, United Kingdom

09:10 We.1.A.2

Damage control, repair and strengthening of concrete arch bridges in China

B. Chen [1]
[1] College of Civil Engineering, Fuzhou University, Fuzhou, China

09:50 **WELCOME ADDRESS**
presented by IIFC

10:00 Break

We.2.A

SHAPE MEMORY ALLOYS (SMAS) FOR ENGINEERING APPLICATIONS (III)

M. Shahverdi, A. Cladera, E. Choi

10:30 We.2.A.1

A simplified model for the shear strength in RC and PC beams, and for punching shear in slabs, without or with shear reinforcement, including steel, FRP and SMA

A. Cladera [1], A. Marí [2], C. Ribas [1], E. Oller [2], J.M. Bairan [2], N. Duarte [2], R. Menduiña [2]
[1] University of Balearic Islands, Palma, Spain; [2] Universitat Politecnica de Catalunya, Barcelona, Spain

10:45 We.2.A.2

The development of memory steel at Empa

C. Czaderski [1], M. Shahverdi [1], E. Ghafoori [1], M. Motavalli [1], C. Leinenbach [1], A. Arabi-Hashemi [1], J. Michels [2], J. Scherer [2]
[1] Empa, Dübendorf, Switzerland; [2] re-fer AG, Brunnen, Switzerland

11:00 We.2.A.3

Improvement of FeMnSi based shape memory alloys yield stress by heat treatment

Y. Yang [1], A. Arabi-Hashemi [1], C. Leinenbach [1], M. Shahverdi [1]
[1] Empa, Dübendorf, Switzerland; [2] ETH Zürich, Switzerland

11:15 We.2.A.4

Axial stiffness of a Fe-SMA during the activation process

Y. Yang [1], M. Breveglieri [1], M. Shahverdi [1,2]
[1] Empa, Dübendorf, Switzerland; [2] University of Tehran, Iran

Room F1

We.2.B

DAMAGE CONTROL, REPAIR AND STRENGTHENING (III)

A. Ilki, M. Breveglieri

10:30 We.2.B.1

Thermal modeling for the prediction of the epoxy adhesive service temperature used in CFRP strengthening of RC bridges

M. Breveglieri [1], C. Czaderski [1]
[1] Empa, Dübendorf, Switzerland

10:45 We.2.B.2

Rehabilitation of Mohammed Al-Qassim Bridge after Fire Attack Using CFRP Sheets: A Case Study

N. Oukaili [1], A. Allawi [1], A. Al-Bayati [1], A. Issa [1], A. Izzat [1]
[1] University of Baghdad, Iraq

11:00 We.2.B.3

Influence of FRP Repair on the Axial Behavior of Fire Damaged Concrete

U. Demir [1], G. Unal [1], A.F. Sert [1], R.O. Calis [1], A. Ilki [1]
[1] Istanbul Technical University, Istanbul, Turkey

11:15 We.2.B.4

Size Effect of RC Beams Strengthened in Shear with EB CFRP L-Shape Laminates

Z.E.A. Benzeguir [1], G. El-Saikaly [1], O. Chaallal [1]
[1] Ecole de technologie superieure (ETS), University of Quebec, Montreal, Canada

We.2.C

SHM – SMART SENSORS (II)

M. Bartholmai, C. Mertz

10:30 **We.2.C.1**

Optimization of frequency ranges in health monitoring of RC frame using embedded PZT sensors

M. Haq [1], T. Naqvi [1], S. Bhalla [2]
[1] Civil Engineering Department, Aligarh Muslim University, Aligarh, India; [2] Civil Engineering Department, Indian Institute of Technology, New Delhi, India

10:45 **We.2.C.2**

Novel concrete crack detection concept by means of shape memory alloy-based fibers

T.T. Dinh [1], S. Hegler [2], I. Navarro de Sosa [3], M. Liebscher [1], M. Reichardt [1], N. Neumann [2], T. Mäder [4], D. Plettemeier [2], W.-G. Drossel [3], V. Mechtcherine [1]
[1] Institute of Construction Materials, TU Dresden, Germany; [2] Chair for RF Engineering, TU Dresden, Germany; [3] Professorship for Adaptronics and Lightweight Design, TU Chemnitz, Germany; [4] Fraunhofer Institute for Machine Tools and Forming Technology, Dresden, Germany

11:00 **We.2.C.3**

Piezoelectric Wafers' Placement Optimization on Tubular Structures – Towards Application on Pipelines

Z. Ismail [1], S. Mustapha [1], H. Tarhini [1]
[1] The American University of Beirut, Lebanon

11:15 **We.2.C.4**

Existing crack monitoring by distributed optical fiber sensor

M. Imai [1], H. Fujihara [2], T. Waki [2], Y. Hironaka [2], Y. Suyama [1], T. Sasaki [1]
[1] Kajima Corporation, Tokyo, Japan; [2] Radioactive Waste Management Funding and Research Center, Tokyo, Japan

We.2.D

NON-DESTRUCTIVE TESTING IN CIVIL ENGINEERING (II)

M.K. Rahman, J. Myers

We.2.D.1

Quantification of digital image correlation applicability related to in-situ proof load testing of bridges

C.O. Christensen [1], E.O.L. Lantsoght [2,3], J.W. Schmidt [1]
[1] Technical University of Denmark, Kgs. Lyngby, Denmark; [2] Polytécnico, Universidad San Francisco de Quito, Ecuador; [3] Delft University of Technology, Delft, Netherlands

We.2.D.2

A Feasibility Study of Laser-based Concrete Stress Measurement Technique

N. Kim [1], J.-J. Lee [1]
[1] Sejong University, Seoul, South Korea

We.2.D.3

Monitoring a concrete bridge girder with the coda wave interferometry method

X. Wang [1], J. Chakraborty [2], P. Klikowicz [2], E. Niederleithinger [1]
[1] BAM, Berlin, Germany; [2] Neostrain, Krakow, Poland

We.2.D.4

Continuous Acoustic Monitoring of a Prestressed Concrete Bridge in Germany

M. Käding [1], G. Schacht [1], S. Marx [2], G. Bolle [3]
[1] MKP GmbH, Hannover, Germany; [2] Institut für Massivbau, Leibniz Universität Hannover, Germany; [3] Fachbereich Bauingenieurwesen, Hochschule Wismar, Germany

	Room F2 + F3	Room F1
11:30	**We.2.A.5** Bond behaviour of near-surface mounted iron-based shape memory alloy bars *B. Schranz[1,2], M. Shahverdi[1,3], C. Czaderski[1]* *[1] Empa, Dübendorf, Switzerland; [2] ETH Zurich, Switzerland; [3] University of Tehran, Iran*	**We.2.B.5** Study on new strengthening method using a soft layer of polyurea and prefabricated CFRP plate for the prevention of peel off *A. Komori[1], S. Sakurai[1], S. Hino[2]* *[1] NIPPON STEEL Chemical & Material Co., LTD., Tokyo, Japan; [2] OITA NATIONAL COLLEGE OF TECHNOLOGY, Oita, Japan*
11:45	**We.2.A.6** Shape memory alloy fibres in fibre-reinforced ultra-high performance concrete – Rheology optimization and bonding behaviour *M. Schleiting[1], S. Khawatmi[1], A. Wetzel[1], J. Thiemicke[1], P. Krooß[1], B. Middendorf[1], E. Fehling[1], T. Niendorf[1], C. Czaderski[2]* *[1] University of Kassel, Germany; [2] Empa, Dübendorf, Switzerland*	**We.2.B.6** Performance of Continuous Concrete Beams with Reinforced FRP Bars and Sheets *S. Aragao Almeida Junior[1], A. Parvin[1]* *[1] The University of Toledo, USA*
12:00	**We.2.A.7** SMA-Reinforced Concrete Shear Walls Subjected to Reverse Cyclic Loading *M. Morcos[1], D. Palermo[1]* *[1] Department of Civil Engineering, York University, Toronto, Canada*	**We.2.B.7** Predicting service life extension and cost due to different repairs on concrete structures under marine environment *A. Petcherdchoo[1], K. Punthutaecha[2]* *[1] King Mongkut's University of Technology North Bangkok, Bangkok, Thailand; [2] Department of Rural Roads, Ministry of Transport, Bangkok, Thailand*
12:15	**We.2.A.8** Retrofitting of Concrete Exterior Beam-Column Joints using NiTi-SMA Sheets *M. Rahman[1], M. Ajmal[2], M. Baluch[1], A. Al-Gahdib[1]* *[1] King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia; [2] Alasala University, Dammam, Saudi Arabia*	**We.2.B.8** Use of cement based grouts in the rehabilitation of concrete dams: a review *J.R. Marques Conde da Silva[1]* *[1] National Laboratory for Civil Engineering, Lisbon, Portugal*
12:30	Lunch	
▶	**We.3.A** **STRENGTHENING, MONITORING AND LIFE-CYCLE ASSESSMENT OF METALLIC STRUCTURES (I)** *E. Ghafoori, R. Helmerich*	**We.3.B** **DAMAGE CONTROL, REPAIR AND STRENGTHENING (IV)** *E. Ferrier, G.P. Lignola*
14:00	**We.3.A.1** Adhesively Bonded CFRP Composites for Steel Strengthening: An overview *E. Ghafoori[1], Q. Yu[2], R. Haghani[3], A. Hosseini[1,4], A. Hadigheh[5], X. Gu[2], M. Motavalli[1], X.-L. Zhao[6]* *[1] Empa, Dübendorf, Switzerland; [2] Tongji University, Shanghai, China; [3] Chalmers University of Technology, Gothenburg, Sweden; [4] EPFL, Lausanne, Switzerland; [5] University of Sydney, Australia; [6] University of New South Wales (UNSW), Sydney, Australia*	**We.3.B.1** Development of Numerical Models for Deep Beams with Discontinuity Regions Strengthened by NSM-CFRP *M. Mansour[1], T. El-Maaddawy[1]* *[1] UAE University, Al Ain, United Arab Emirates*
14:15	**We.3.A.2** Simplified FE model predicting the bending behaviour of corroded tubular steel members rehabilitated using CFRP *J.M. George[1], M. Kimiaei[1], M. Elchalakani[1]* *[1] The University of Western Australia, Perth, Australia*	**We.3.B.2** EBROG method to strengthen heat-damaged concrete with CFRP sheets *A. Tajmir-Riahi[1], N. Moshiri[1,2], D. Mostofinejad[1]* *[1] Isfahan University of Technology (IUT), Isfahan, Iran; [2] Empa, Dübendorf, Schwitzerland*

11:30 **We.2.C.5**

Distributed Fiber Optics Monitoring of the Lago Bianco Dam in Switzerland

T. Crameri [1], A. Höttges [2], C. Rabaiotti [2]
[1] Repower, Poschiavo, Switzerland; [2] HSR, Rapperswil, Switzerland

We.2.D.5

Magnetic measurement of corrosion in a steel structure using extremely low-frequency eddy current testing without surface treatment

K. Tsukada [1], S. Wakabayashi [1], M. Hayashi [1], T. Saitoh [1], T. Tomioka [1], K. Sakai [1], T. Kiwa [1], Y. Fujino [2]
[1] Okayama University, Okayama, Japan; [2] Yokohama National University, Yokohama, Japan

11:45 **We.2.C.6**

Assessment of crack patterns along plain concrete tunnel linings using distributed fiber optic sensing

M. Winkler [1], C.M. Monsberger [1], W. Lienhart [1], A. Vorwagner [2], M. Kwapisz [2]
[1] Graz University of Technology, Institute of Engineering Geodesy and Measurement Systems, Graz, Austria; [2] AIT Austrian Institute of Technology GmbH, Vienna, Austria

We.2.D.6

Update of Service Life Design with Monitoring Data from Corrosion Sensors

G. Kapteina [1], T.F. Mayer [2]
[1] HafenCity Universität, Hamburg, Germany; [2] Ingenieurbüro Schießl Gehlen Sodeikat, Munich, Germany

12:00 **We.2.C.7**

Monitoring high thermal performance concrete for concentrated solar power plants with fiber optic sensors

R. Ruiz-Lombera [1], T. Grandal [1], S. Fraga [1]
[1] Aimen technology centre, Porriño, Pontevedra, Spain

We.2.D.7

Vibration based Condition Assessment of Deteriorated Reinforced Concrete

A.S. Kırlangıç [1]
[1] Bahcesehir University, Istanbul, Turkey

12:15 **We.2.C.8**

Static load monitoring of a concrete bridge using a high-precision distributed fiber optic sensor system

A. Wosniok [1], R. Jansen [2], L. Cheng [2], P. Toet [2], E. Doppenberg [2], W. de Jong [2], S. Chruscicki [1]
[1] BAM, Berlin, Germany; [2] TNO, Delft, Netherlands

We.2.D.8

Structural health monitoring of Artemio Franchi Stadium in Florence, Italy: measurement using interferometric radar

L. Miccinesi [1], M. Pieraccini [1], G. Terenzi [1], I. Costoli [2], P. Spinelli [1], G. Mazzieri [1]
[1] University of Florence, Italy; [2] University of Udine, Italy

We.3.C

▶ **PERFORMANCE AND DAMAGE ASSESSMENT**

J. Shah, J. Myers

14:00 **We.3.C.1**

Detection of bolt loosening through ultrasonic imaging

J. Shah [1], S. Majhi [1], A. Mukherjee [1]
[1] Curtin University, Perth, Australia

14:15 **We.3.C.2**

Duration-based Forecasting of Bridge Condition with Non-Parametric Kaplan-Meier Survival Functions

R. Goyal [1], M. Whelan [2], T. Cavalline [2]
[1] NRC Research Associateship, McLean, Virginia, USA;
[2] University of North Carolina at Charlotte, USA

Room F2 + F3

14:30 **We.3.A.3**

Added value of regular in-service visual inspection to the fatigue reliability of structural details in steel bridges

B. Hashemi [1], J. Maljaars [1], H.H. Snijder [1]
[1] Eindhoven University of Technology, Eindhoven, Netherlands

14:45 **We.3.A.4**

Local and Distortional Buckling Behaviour of Cold-Formed Steel Sigma Beam-Column Profiles

F. Öztürk [1], M. Şentürk [1,2], S. Pul [1], I. Hajirasouliha [2]
[1] Karadeniz Technical University, Trabzon, Turkey; [2] The University of Sheffield, United Kingdom

15:00 **We.3.A.5**

Strength of concrete with FRP fabric confinement using geopolymer bonding agent after exposure to high temperature

M. Elmegbr [1], S. Sarker [2], P. Sarker [1]
[1] Curtin University, Perth, Australia; [2] Chittagong University of Engineering and Technology, Chittagong, Bangladesh

15:15 **We.3.A.6**

Damage experiment on a steel plate girder bridge and local damage detection utilizing traffic-induced vibration

C.-W. Kim [1], Y. Goi [1], T. Mimasu [1]
[1] Kyoto University, Kyoto, Japan

15:30 **We.3.A.7**

Fatigue performance and evaluation of horizontal gusset plate web gap details in steel bridges

Y. Wang [1], J. Feng [1], C. Wang [1], B. Cui [1], L. Duan [1]
[1] School of Highway, Chang'an University, Xi'an, China

15:45

16:00 Break

We.4.A

▶ **DURABILITY AND CORROSION MONITORING OF CONCRETE INFRASTRUCTURES**

U. Angst, S. Keßler

16:30 **We.4.A.1**

The new DGZfP Specification B12 „Corrosion Monitoring of Reinforced Concrete Structures"

J. Harnisch [1], C. Dauberschmidt [2], G. Ebell [3], T.F. Mayer [4]
[1] Fachhochschule Münster, Germany; [2] Hochschule München, Germany; [3] BAM, Berlin, Germany; [4] Ingenieurbüro Schießl Gehlen Sodeikat GmbH, München, Germany

Room F1

We.3.B.3

Assessment of load transfer length in textile reinforced cementitious matrix composites

M. Saidi [1], A. Gabor [1]
[1] Laboratory of Composite Materials for Construction (LMC^2), Lyon, France

We.3.B.4

Rocking concrete shear walls with self-centring friction dampers for seismic protection of building structures

F. Mohammadi Darani [1], K. Sahami [1], P. Zarnani [1], S. Veismoradi [1], H. Bagheri [2], P. Quenneville [2], E. Haemmerle [1]
[1] Auckland University of Technology (AUT), Auckland, New Zealand; [2] The University of Auckland, New Zealand

We.3.B.5

Effect of Internal and External Reinforcement Ratios on RC Beams Strengthened with NSM Prestressed Fiber Reinforced Polymer Rods

A. Parvin [1], J. Raad [1], S. Aragao Almeida Junior [1]
[1] The University of Toledo, USA

We.3.B.6

FE-Modelling Techniques for Structural Capacity Assessment of Corroded Reinforced Concrete Structures

A. Kagermanov [1], I. Markovic [1]
[1] University Applied Science Rapperswil (HSR), Rapperswil, Switzerland

We.3.B.7

Structural upgrading of the longest and skewed span of the Yverdon Viaduct

D. Papastergiou [1], C. Candolfi [2]
[1] Swiss Federal Roads Office, Bern, Switzerland; [2] VSL Schweiz AG, Bern, Switzerland

We.3.B.8

FRP vs FRCM in flexural strengthening of masonry

G. Ramaglia [1], G. Crisci [2], F. Fabbrocino [1], G.P. Lignola [2], A. Prota [2]
[1] Telematic University Pegaso, Department of Engineering, Napoli, Italy; [2] University of Naples „Federico II", Department of Structures, Napoli, Italy

We.4.B

DURABILITY ISSUES AS RELATED TO HARSH ENVIRONMENTS – FIRE PROTECTION SYSTEMS

P. Sarker, J. Myers

We.4.B.1

Durability Evaluation of Embedded GFRP Rebars in Concrete Bridges after More Than Ten Years of Service

A. Al-Khafaji [1], J. Myers [1]
[1] Missouri University of Science and Technology, Rolla, USA

14:30 **We.3.C.3**

Performance Assessment of Transversely Stressed Deck Unit Bridges with Damaged Transversely Stressing Bars through Field Measurements

H. Ngo [1], M. Hourigan [2], N. Lake [1]
[1] Australian Road Research Board, Brisbane, Australia;
[2] Queensland Department of Transport and Main Roads, Brisbane, Australia

14:45 **We.3.C.4**

Long term monitoring of a UHPFRC-strengthened bridge deck slab using strain gauges

B. Sawicki [1], E. Brühwiler [1]
[1] Laboratory of Maintenance and Safety of Structures, École Polytechnique Fédérale de Lausanne, Switzerland

15:00 **We.3.C.5**

Design Optimisation of Cable-Stayed Bridge Based on Cable-Bridge Resonance Control

Y. Liu [1], Q. Han [1], K. Xu [1]
[1] Beijing University of Technology, Beijing, China

15:15 **We.3.C.6**

Reliability assessment of cable-stayed bridge subjected to blast loading

C.D. Tetougueni [1], P. Zampieri [1]
[1] University of Padua, Italy

We.4.C

▶ **DYNAMIC VIBRATION-BASED MONITORING, SEISMIC PERFORMANCE**

M. Motavalli, E. Martinelli

We.4.D

PRACTICAL APPLICATIONS AND CASE STUDIES (I)

A. Ilki, M. Hueppi

16:30 **We.4.C.1**

Dynamic load monitoring of a concrete bridge using a fiber optic Distributed Acoustic Sensing (DAS) system

L. Cheng [1], R. Jansen [1], H. Burggraaf [1], W. de Jong [1], P. Toet [1], E. Doppenberg [1]
[1] TNO, Delft, Netherlands

We.4.D.1

Mobile LIBS-System for condition assesment of concrete structures on-site

G. Wilsch [1], T. Günther [1], S. Millar [1], T. Völker [1]
[1] BAM, Berlin, Germany

	Room F2 + F3	Room F1
16:45	**We.4.A.2** General aspects on the assessment of reliability of corrosion monitoring systems *S. Keßler[1], D. Kanzler[2]* *[1] TU München, Germany; [2] applied NDT Reliability, Berlin, Germany*	**We.4.B.2** Corrosion Resistance of Calcium Aluminate Cement Concrete Subjected to Sulfuric Acid *H. Al-Khalifah[2], M. Rahman[1], A. Al-Gadhib[1], S. Ahmed[1], S. Al-Dulaijan[1], A. Al-Gahtani[1]* *[1] King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia; [2] Consulting Services Department Saudi Aramco, Dhahran, Saudi Arabia*
17:00	**We.4.A.3** Novel sensor for non-destructive durability monitoring in reinforced concrete *Y. Seguí Femenias[1], U. Angst[1]* *[1] ETH Zurich, Switzerland*	**We.4.B.3** Experimental investigation on physico-mechanical properties of natural building stones exposed to high temperature *M. Vigroux[1], J. Eslami[1], A.-L. Beaucour[1], A. Bourgès[2], A. Noumowé[1]* *[1] Laboratoire de Mécanique et Matériaux du Génie Civil – Université de Cergy-Pontoise, Cergy-Pontoise, France; [2] Laboratoire de Recherche des Monuments Historiques – Ministère de la Culture et de la Communication, Champs-sur-Marne, France*
17:15	**We.4.A.4** On-site monitoring for studying the effects of repair measures on corroding steel in chloride contaminated concrete *F. Binder[1], F. Pruckner[2]* *[1] Asfinag Service GmbH, Vienna, Austria; [2] ZT-Büro Pruckner, Euratsfeld, Austria*	**We.4.B.4** Effect of Harsh Temperature Environment on Strength and Durability of Normal and High Strength Concrete *M. Haq[1], A.F. Hashmi[1], M.A. Khan[1], J. Raju[2]* *[1] Aligarh Muslim University, Aligarh, India; [2] Indian Institute of Technology Delhi, New Delhi, India*
17:30	**We.4.A.5** Corrosion monitoring of cracked concrete structures – state of knowledge and case studies *T.F. Mayer[1], F. Hiemer[2], F. Wich[1]* *[1] Ingenieurbüro Schiessl Gehlen Sodeikat, München, Germany; [2] Center for Building Materials, TU München, Germany*	**We.4.B.5** The Axial Loading Capacity of Reinforced Concrete Columns Exposed to High Temperature *A.H. Eskandani[1], M. Şentürk[2], S. Pul[1], I. Hajirasouliha[2]* *[1] Karadeniz Technical University, Trabzon, Turkey; [2] The University of Sheffield, United Kingdom*
17:45	**We.4.A.6** Flying corrosion inspection robot for corrosion monitoring of civil structures – First results *P. Pfändler[1], K. Bodie[1], U. Angst[1], R. Siegwart[1]* *[1] ETH Zurich, Switzerland*	
18:00	**We.4.A.7** Numerical Modelling of Corroded Reinforced Concrete Beams Based on Visual Inspection Data *H. Nasser[1], C. Van Steen[1], R. Vrijdaghs[1], A.A. Torres-Acosta[2], L. Vandewalle[1], E. Verstrynge[1]* *[1] KU Leuven, Belgium; [2] Universidad Marista de Querétaro, Mexico*	
19:00	Conference Dinner at Biosphäre Potsdam	

16:45 **We.4.C.2**

Dynamic Monitoring of Steel and Concrete Offshore Structures

M. Rizzo [1], O. Spadaccini [1]
[1] DICeA, University of Florence, Italy

We.4.D.2

Long-Term-Monitoring of CFRP-cables over almost a quarter of a century

P. Anderegg [1], R. Broennimann [1], U. Meier [1]
[1] Empa, Duebendorf, Switzerland

17:00 **We.4.C.3**

Vibration Analysis of Structures using a Drone (UAV) based Mobile Sensing Platform

R. Herrmann [1], A. Moortgat-Pick [2], S. Marx [2]
[1] BAM, Berlin, Germany; [2] Institute of Concrete Construction (IfMa), Leibniz University Hannover, Germany

We.4.D.3

Structural Health Monitoring of Bridges in Mexico – Case Studies

J.R. Gaxiola-Camacho [1], J.A. Quintana-Rodríguez [2], G.E. Vazquez-Becerra [1], F.J. Carrion-Viramontes [2], J.R. Vazquez-Ontiveros [1], F.J. Lopez-Varelas [1]
[1] The Autonomous University of Sinaloa, Culiacan, Mexico; [2] Instituto Mexicano del Transporte, Queretaro, Mexico

17:15 **We.4.C.4**

Assessing Seismic Failure Probability of Hospital Emergency Power Supply Systems and Software Development

C.-H. Lin [1], C.-T. Yang [1], Y.-X. Lin [1], K.-C. Chen [2]
[1] National Center for Research on Earthquake Engineering, Taipei, Taiwan (Republic of China); [2] Institute of Applied Mechanics, National Taiwan University, Taipei, Taiwan (Republic of China)

We.4.D.4

Damage Assessment of Concrete Sulfur Storage Structure in Petrochemical Industry

M. Rahman [1], H. Al-Khalifah [2], S. Al-Ghamdi [2], M. Ibrahim [1], F. Al-Yousef [1], A. Al-Gadhib [1]
[1] King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia; [2] Consulting Services Department, Saudi Aramco, Dhahran, Saudi Arabia

17:30 **We.4.C.5**

Estimating seismic interstory drifts of building structures using time-varying shear model with acceleration data

X. Li [1], X. Yu [1]
[1] School of Civil Engineering, Chongqing University, Chongqing, China

We.4.D.5

Fracture characteristics of cold jointed concrete identified by acoustic emission technique

S. Tayfur [1], N. Alver [1], Z. Turan [1], O. Andic Cakir [1]
[1] Ege University, Izmir, Turkey

17:45 **We.4.C.6**

Reconstruction Cost and Insurance Refunding Empirical Evidences for Long-span-beam Buildings Struck by the 2012 Emilia-Romagna Earthquake

L. Rossi [1]
[1] RWTH, Aachen, Germany

We.4.D.6

Satellite-based InSAR Monitoring – Validation on Victoria Bridge in Montreal, Canada

D. Cusson [1], I. Ozkan [1]
[1] National Research Council Canada, Ottawa, Canada

18:00 **We.4.C.7**

Seismic Performance of Reinforced Concrete Girders of an Existing Building Constructed in 1971

H. Araki [1]
[1] Hiroshima Institute of Technology, Hiroshima, Japan

Room F2 + F3

Th.1.A

KEYNOTE PRESENTATIONS

A. Ilki

08:30 **Th.1.A.1**

Extending the Strengthening Potentialties of Near Surface Mounted Technique: From Experimental Evidence to Advanced Numerical Simulations

J.A.O. de Barros [1]
[1] ISISE, University of Minho, Guimarães, Portugal

09:10 **Th.1.A.2**

Recent Advances on Assessment of Seismic Performance of Existing Structures

A. Yakut [1]
[1] Middle East Technical University, Department of Civil Eng., Ankara, Turkey

09:50 Break

Th.2.A

TESTING, INSPECTION, MONITORING AND REPAIR OF OFFSHORE WIND ENERGY CONVERTERS

M. Baeßler, R. Schneider

10:20 **Th.2.A.1**

Comparison of cracks formed in scaled grouted connection of offshore energy structures under static and cyclic loads

G. Hüsken [1], M. Shamsuddoha [1], M. Thiele [1], M. Baeßler [1], H.-C. Kühne [1]
[1] BAM, Berlin, Germany

10:35 **Th.2.A.2**

Restoration of structural integrity – a comparison of various repair concepts for wind turbine rotor blade shells

C. Ghafafian [1], B. Popiela [1], D. Nielow [1], V. Trappe [1]
[1] BAM, Berlin, Germany

10:50 **Th.2.A.3**

Comparison of fatigue crack detection methods for high-cyclic loaded steel structures

M. Thiele [1], R. Makris [1], F. Hille [1]
[1] BAM, Berlin, Germany

11:05 **Th.2.A.4**

Effect of repair models on risk-based optimal inspection strategies for support structures of offshore wind turbines

R. Schneider [1]
[1] BAM, Berlin, Germany

Room F1

Th.2.B

LABORATORY TEST OF THE EFFECTIVITY OF EXTERNAL NON FRP STRENGTHENING LAYERS

G. Ferrara, B. Chen

Th.2.B.1

Tensile behaviour and durability assessment of Flax Textile Reinforced Mortar composite systems

G. Ferrara [1], C. Caggegi [2], A. Gabor [2], E. Martinelli [1]
[1] University of Salerno, Fisciano (SA), Italy; [2] Université Claude Bernard Lyon 1, Villeurbanne, France

Th.2.B.2

Shear strengthening of masonry walls with Flax Textile Reinforced Mortar composite systems

G. Ferrara [1], C. Caggegi [2], E. Martinelli [1], A. Gabor [2]
[1] University of Salerno, Fisciano (SA), Italy; [2] Université Claude Bernard Lyon 1, Villeurbanne, France

Th.2.B.3

Experimental study on the effect of the Prestressed Concrete Cylinder Pipe strengthened by external prestressed strengthening strands

L. Zhao [1], T. Dou [1], B. Cheng [1]
[1] China Institute of Water Resources and Hydropower Research, Beijing, China

Th.2.B.4

Effect of carbon textile treatment and embedded textile length on textile/matrix interface behaviour from pull-out test

M.T. Tran [1], X.H. Vu [1], E. Ferrier [1]
[1] Université Claude Bernard Lyon 1, Villeurbanne, France

Th.2.C

SHM – STRUCTURAL HEALTH MONITORING ON BRIDGES, ADVANCED INSPECTION AND TESTING

A. Miyamoto, W. Lienhart

10:20 Th.2.C.1

Structural Health Monitoring of a post-tensioned concrete bridge using wireless sensor system: deployment and evaluation

N. Navabian [1], S. Beskhyroun [1]
[1] Auckland University of Technology, Auckland, New Zealand

10:35 Th.2.C.2

A double-pass method for bridge assessment considering surface roughness using normalized contact point responses

Y. Zhan [1], F.T.K. Au [1]
[1] Department of Civil Engineering, The University of Hong Kong, China

10:50 Th.2.C.3

Remote microtremor monitoring of railway bridge pier for scour detection

S. Kitagawa [1], M. Shinoda [1], H. Yao [1], C.-W. Kim [2], Y. Goi [2], K. Yoshitome [2], Y. Hamada [3]
[1] Fuji Electric Co. LTD., Tokyo, Japan; [2] Kyoto University, Kyoto, Japan; [3] West Japan Railway Company, Osaka, Japan

11:05 Th.2.C.4

Effect of Ambient Temperature on Behavior of a Steel Arch Bridge Based on SHM Data

J. Gao [1], B. Wang [1], J. Wang [1]
[1] Department of Civil Engineering, Xiamen University, Xiamen, China

Th.2.D

PRACTICAL APPLICATIONS AND CASE STUDIES (II)

J. Barros, E. Brühwiler

Th.2.D.1

Long-Term Mode Shape Variations of Hagia Sophia with Environmental Factors

E. Dar [1], E. Çaktı [1]
[1] Boğaziçi University, Kandilli Observatory Earthquake Research Institute, Kandilli, İstanbul, Turkey

Th.2.D.2

First Application of Base Isolation in an Existing Residential Building in Istanbul

H. Karayiğit [1], Ö. Özkul [1]
[1] Freysaş Freyssinet Yapı Sistemleri San. A.Ş., İstanbul, Turkey

Th.2.D.3

GPS Performance Assessment and Analysis, El Carrizo and Juarez Bridge in Sinaloa Mexico

G.E. Vazquez [1], J.R. Gaxiola-Camacho [1], F.J. Carrion-Viramontes [2], J.A. Quintana-Rodríguez [2], J.R. Vazquez-Ontiveros [1], G.M. Guzman-Acevedo [1]
[1] The Autonomous University of Sinalao, Culiacan, Mexico; [2] Instituto Mexicano del Transporte, Queretaro, Mexico

Th.2.D.4

Long-Term Vibration Monitoring and Model Updating of Gageocho Ocean Research Station

J.-H. Yi [1,2], B. Kim [2], I.-K. Min [1], J.S. Shim [1]
[1] Korea Institute of Ocean Science and Technology, Busan, South Korea; [2] Korea Maritime and Ocean University, Busan, South Korea

	Room F2 + F3	Room F1
11:20	**Th.2.A.5** Investigation of the salinization of metal surfaces in marine and offshore environment – test methods and challenges *M. Babutzka [1], A. Burkert [1]* *[1] BAM, Berlin, Germany*	**Th.2.B.5** Experimental Investigation on the Bond Behavior of Steel Fiber Reinforced Mortar (SFRM) applied onto Masonry Substrates *N. Simoncello [1], J. Gonzalez-Libreros [1], P. Zampieri [1], C. Pellegrino [1]* *[1] University of Padua, Italy*
11:35		**Th.2.B.6** Strengthening of Reinforced Concrete Beams with Fabric Reinforced Geopolymer Composite *X. Shen [1], W. Chen [1], B. Li [1], C.M. Hancock [1]* *[1] University of Nottingham Ningbo China, Ningbo, China*
12:05	Lunch	
▶	**Th.3.A** **VISIONARY CONCEPTS, DEEP LEARNING** *J. Myers, S. Cho*	**Th.3.B** **STRENGTHENING, MONITORING AND LIFE-CYCLE ASSESSMENT OF METALLIC STRUCTURES (II)** *E. Ghafoori, Q.-Q. Yu*
13:30	**Th.3.A.1** Self-Prestressed Carbon-Reinforced High Performance Concrete Elements *M. Wyrzykowski [1], P. Lura [1], G. Terrasi [1]* *[1] Empa, Dübendorf, Switzerland*	**Th.3.B.1** Full scale cast iron girders reinforced with CFRP – flexural testing *S. Moy [1]* *[1] University of Southampton, United Kingdom*
13:40	**Th.3.A.2** Automated Infrastructure Inspection based on Digital Twins and Machine Learning *P. Furtner [1], E. Forstner [2], A. Karlusch [2]* *[1] VCE Vienna Consulting Engineers ZT GmbH, Vienna, Austria; [2] Palfinger Structural Inspection GmbH, Vienna, Austria*	**Th.3.B.2** Smart SMA-based system for fatigue strengthening of cracked metallic bridge connections *M. Izadi [1,2], M. Motavalli [1,2], E. Ghafoori [1]* *[1] Empa, Dübendorf, Switzerland; [2] University of Tehran, Iran*
14:00	**Th.3.A.3** Reinforced Masonry Retention Wall Model Using Artificial Neural Networks *E.S. Hernandez [1], J.A. Alvarado-Contreras [2], A.A. López-Inojosa [2], J.J. Myers [1]* *[1] Missouri University of Science and Technology, Rolla, USA; [2] University of Los Andes, Merida, Venezuela*	**Th.3.B.3** Monitoring and control of the longest suspension bridge in Brazil during its complex rehabilitation process *C. Barbosa [1], R. Martins [2], C. Alves [3], P. Faro [2]* *[1] HBM FiberSensing, Porto, Portugal; [2] Teixeira Duarte, São Paulo, Brazil; [3] Spectris do Brasil, São Paulo, Brazil*
14:15	**Th.3.A.4** Modeling of Bimodulus Materials with Applications to the Analysis of the Brazilian Disk Test *E.S. Hernandez [1], J.A. Alvarado-Contreras [2], A.A. López-Inojosa [2], J.J. Myers [1]* *[1] Missouri University of Science and Technology, Rolla, USA; [2] University of Los Andes, Mérida, Venezuela*	**Th.3.B.4** Experimental study on repairing of fatigue-cracked steel plates using high strength bolts and CFRP strips *Z. Lv [1], X. Jiang [1], X. Qiang [1], J. Zhang [2]* *[1] College of Civil Engineering, Tongji University, Shanghai, China; [2] JSTI Group, Nanjing, China*

11:20 **Th.2.C.5**

Remote Monitoring System for Road Condition Assessment and Its Application

A. Miyamoto [1]
[1] Yamaguchi University, Ube, Japan

Th.2.D.5

Crack monitoring in the Baptistery of the Euphrasian Basilica in Poreč

D. Grandić [1], P. Šćulac [1], I. Ružić [1], N. Krvavica [1]
[1] University of Rijeka, Faculty of Civil Engineering, Rijeka, Croatia

11:35 **Th.2.C.6**

New possibilities for concrete analysis 4.0 with the Laser-Induced Breakdown Spectroscopy (LIBS)

C. Gottlieb [1], C. Bohling [1], G. Wilsch [2]
[1] Secopta analytics GmbH, Teltow, Germany; [2] BAM, Berlin, Germany

Th.2.D.6

Measured and computed dynamic characteristics of a hospital building in Bucharest

D. Köber [1], A. Aldea [1], R. Enache [1], P. Semrau [2], F. Weber [3]
[1] Technical University of Civil Engineering Bucharest, Romania; [2] MAURER SE, Munich, Germany; [3] Maurer Switzerland GmbH, Zurich, Switzerland

11:50 **Th.2.C.7**

Long Term Skid Resistance of Exposed Aggregate Concrete Pavement

M. Rith [1], Y.K. Kim [1], S.W. Lee [1]
[1] Gangneung-Wonju National University, Gangneung-si, South Korea

Th.3.C

SHM – SYSTEM IDENTIFICATION AND MODEL UPDATING

E. Brühwiler, A. Miyamoto

13:30 **Th.3.C.1**

Assessment of reinforced concrete structures performance under environment aggressiveness for durability monitoring

P. Alonso [1], F. Rodriguez [1], J. Leon [1]
[1] Polytechnic University of Madrid, Spain

13:45 **Th.3.C.2**

Monitoring Concrete Strength Parameters for Gravity Dam using Strain Energy Based Structural Health Monitoring Technique

S. Bagchi [1], A. Bagchi [1]
[1] Concordia University, Montreal, Canada

14:00 **Th.3.C.3**

A comparison of greedy and global searches for measurement-system design in bridge load testing

N.J. Bertola [1,2], I.F.C. Smith [1,2]
[1] Singapore ETH Centre, Singapore; [2] EPFL, Lausanne, Switzerland

14:15 **Th.3.C.4**

Traffic and Temperature Effects Monitoring on Bridges by Optical Strands Strain Sensors

F.-B. Cartiaux [1], P. Pelletier [1], J. Semiao [1]
[1] OSMOS Group, Paris, France

	Room F2 + F3	Room F1
14:30	**Th.3.A.5** Artificial intelligence-based estimation of the consumed fatigue-related lifetime for an operating wind turbine support structure *M. Ratkovac [1], I. Mueller [1], R. Höffer [1]* *[1] Ruhr-Universität Bochum, Germany*	**Th.3.B.5** Experimetal research on durability of bonding reinforcement method for distortion-induced fatigue in steel bridges *C. Wang [1], Y. Wang [1], B. Cui [1], J. Feng [1]* *[1] School of Highway, Chang'an University, Xi'an, China*
14:45	**Th.3.A.6** Deep Learning-based Defect Detection and Assessment for Engineering Structures *Z.Y. Wu [1], R. Kalfarisi [1]* *[1] Bentley Systems, Incorporated, Watertown, USA*	**Th.3.B.6** Application of IRT for assessing the process of delamination of hybrid steel/FRP elements *M. Dakhel [1], T. Donchev [1], Q.N. Mehraj [1]* *[1] Kingston University London, Kingston Upon Thames, United Kingdom*
15:00	**Th.3.A.7** Moving Beyond the Romans: Deep Learning and Road Maintenance *M. DeSantis [1], C. Mertz [1]* *[1] RoadBotics, Pittsburgh, USA*	**Th.3.B.7** Mechanical behaviour of corroded prestressing steel strand *C. Jeon [1], J. Lee [1], C. Shim [1]* *[1] Chung-Ang University, Seoul, South Korea*
15:15	**Th.3.A.8** Application of deep learning-based crack assessment technique to civil structures *S. Cho [1], B. Kim [1], G. Kim [1]* *[1] University of Seoul, South Korea*	**Th.3.B.8** Strengthening Effect of CFRP Bonded Steel Plate with Insufficient Bond Length *Y. Hidekuma [1], T. Ishikawa [2]* *[1] NIPPON STEEL Chemical & Material Co., Ltd., Tokyo, Japan;* *[2] Kansai University, Osaka, Japan*
15:30	Break	
15:45	Closing and Awards, Announcement of next SMAR Conference	

14:30 **Th.3.C.5**

Structural Health Monitoring results as an input for asset management of offshore wind turbine support structures

S. Tewolde [1,2], R. Höffer [1], H. Haardt [2], J. Krieger [2]
[1] Ruhr-Universität Bochum, Germany; [2] airwerk GmbH, Emstek, Germany

14:45 **Th.3.C.6**

New SHM applications in cable-supported bridges – Case studies

N. Meng [1], M. Treacy [1], S. Adam [2], A. Paciacconi [1], T. Richli [1]
[1] Mageba SA, Bulach, Switzerland; [2] Mageba GmbH, Uslar, Germany

15:00 **Th.3.C.7**

What added value can SHM bring to my construction project or structure maintenance programme?

M. Treacy [1], N. Meng [1], A. Paciacconi [1], T. Richli [1]
[1] Mageba SA, Bulach, Switzerland

P1 Val-LIBS: A novel attempt to decipher the transport processes in concrete – A case study
M.B. Lierenfeld[1], N. Metthez[1], P. Truffer[1]
[1] Valtest AG, Lalden, Switzerland

P2 Corrosion Damage Mode Testing and Damage Cause Analysis of Sodium Hypochlorite Concrete Tank Structure for Coastal Nuclear Power Plant
J. Zhou[1], S. Chen[1], Z. Wang[1]
[1] China Nuclear Power Operation Technology Corporation (CNPO), LTD, Wuhan, China

P3 Numerical Investigation of RC Beam Strengthened with UHPFRC Layers Using Cohesive Surface Bonding Method
M. Al-Huri[1], S. Ahmad[1], M. Al-Osta[1], A. Al-Gadhib[1], M.K. Rahman[1]
[1] King Fahd Univ. of Petroleum & Minerals, Dhahran, Saudi Arabia

P4 Repairing and strengthening steel-corroded RC members using the cathodic protection and by mounting a stainless steel rebar
A. Kamiharako[1], S. Sasamori[1], T. Miura[1], A. Kashima[2], Y. Kondo[3]
[1] Hirosaki University, Hirosaki, Aomori, Japan; [2] Sumitomo Osaka Cement Co., Ltd, Tokyo, Japan; [3] Aichi Steel Corporation, Tokai, Aichi, Japan

P5 Smart electronic helper for long-term monitoring of bridges and building structures
S. Johann[1], C. Strangfeld[1], D. Zimmek[1], M. Bartholmai[1]
[1] BAM, Berlin, Germany

P6 Application of Time Series Methods on Long-Term Structural Monitoring Data for Fatigue Analysis
M. Ahmadivala[1], B. Sawicki[2], E. Brühwiler[2], T. Yalamas[1], N. Gayton[3], C. Mattrand[3], A. Orcesi[4]
[1] PHIMECA Engineering, Cournon d'Auvergne, France; [2] EPFL, Lausanne, Switzerland; [3] Université Clermont Auvergne, CNRS, SIGMA Clermont, Institut Pascal, Clermont-Ferrand, France; [4] IFSTTAR, Marne-la-Vallée, France

P7 Statistical approach-based automated determination of an optimal subset size for digital image correlation analysis
M. Kang[1], Y.-K. An[1]
[1] Sejong University, Seoul, South Korea

P8 Acoustic Emission and damage monitoring in RC beams under cyclic loading
H. Xargay[1], M. Ripani[2], P. Folino[2], M. Gómez[1], E. Martinelli[3]
[1] Comisión Nacional de Energía Atómica (CNEA), Departamento ICES, Buenos Aires, Argentina; [2] Universidad de Buenos Aires, Facultad de Ingeniería, INTECIN (UBA-CONICET), Buenos Aires, Argentina; [3] Università di Salerno, Dipartimento di Ingegneria Civile, Salerno, Italy

Pre-conference tour to ship‘s hoist project Niederfinow

The Niederfinow boat lift is the oldest working ship lift in Germany. It lies at the eastern end of the Oder-Havel-Kanal in Niederfinow/Brandenburg and overcomes a difference in altitude of 36 metres.
Parallel, the new ship’s hoist Niederfinow is being built, which will meet the parameters of a Class V European waterway, thus meeting European standards and will replace the old hoist by 2025 at the latest.

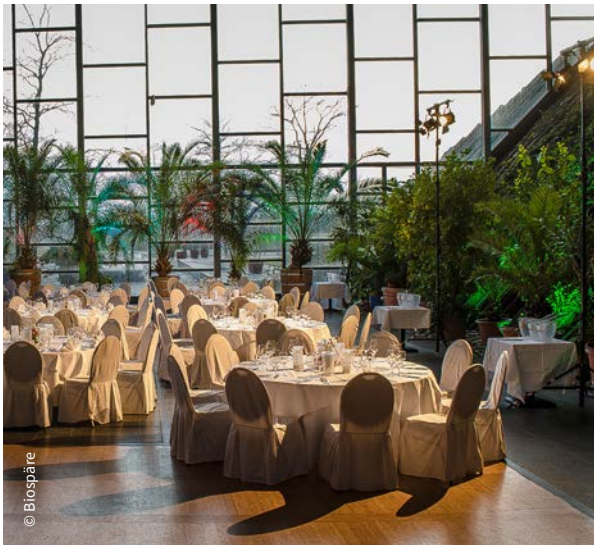
The tour to the Niederfinow boat lift starts at 07:30 h at the conference hotel. At about 9:30 h we will reach our destination. After a short coffee break with snacks and refreshments we will be welcomed in the visitor‘s pavilion of the Water and Shipping Authority. After about half an hour‘s introduction, our sightseeing tour with technical focus starts on the old and new ship lift.
After that and with many impressions, we will have lunch.
The tour ends at about 17:00 h at the conference hotel.

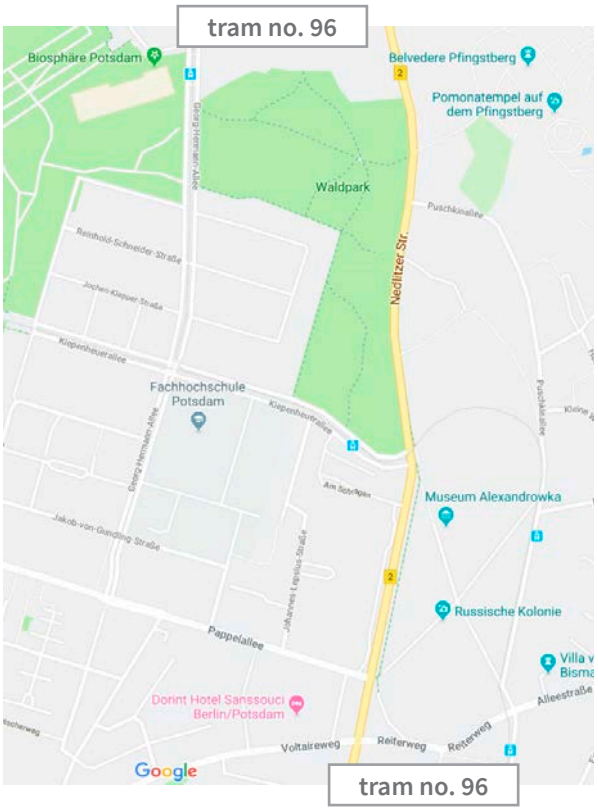
Date: **Monday, 26 August 2019, 07:30 – 17:00 h**
Start/End: **Dorint Hotel Sanssouci Berlin-Potsdam**

Get-together and technical visits at BAM

The Bundesanstalt für Materialforschung und -prüfung (BAM) is a senior scientific and technical federal institute with responsibility to the Federal Ministry for Economic Affairs and Energy.
BAM tests, researches and advises to protect people, the environment and material goods and sets and represents high standards for safety in technology and chemistry for Germany and for its global markets.
After welcoming we invite you for snacks and drinks.
From 19:30 h laboratory visits take place in department 7 „Safety of Structures“ and department 8 „Non-Destructive Testing”. In advance, the participants are divided into 2 groups.
At 20:30 h and 21:00 h busses will bring you back to the conference hotel in Potsdam.

Date: **Tuesday, 27 August 2019, 18:00 – 22:00 h**
Start: **bus transfer starts at 17:30 h at Dorint Hotel Sanssouci Berlin-Potsdam**
End: **about 22:00 h at Dorint Hotel Sanssouci Berlin-Potsdam**





Conference Dinner at „Biosphäre Potsdam“

In the centre of Potsdam is a place with a holiday-atmosphere 365 days a year – the Biosphäre Potsdam. The jungle landscape of the Biosphäre with over 20.000 beautiful plants, many exotic animals and an hourly thunderstorm with thunder and lightning takes you to a world far away. Your journey begins at the waterfall and continues on intertwined paths to the butterfly house and to the high-trail up in the treetops.
Biosphäre Potsdam – the mystical tropical world just outside Berlin’s gates: Go on a fascinating journey through the beautiful world of the jungle with free flying birds, terrariums with insects and reptiles, bird aviaries, and an underwater world akin to a historical submarine with colorful fishes.

From 19:00 h we welcome you at the Biosphäre Potsdam. After the opening of the evening the buffet will be opened. Afterwards you are invited to visit the tropical garden and the underwater world. The evening ends at about 24:00 h.

The Biosphäre can be reached by foot (about 20 minutes) or by tram no. 96 from station „Potsdam, Reiterweg/ Alleestr.“ (about 320 m) in direction Potsdam, Campus Jungfernsee until station „Potsdam, Volkspark“, then about 100 m by foot (about 15 minutes).

Date: **Wednesday, 28 August 2019, 19:30 – 24:00 h**
Place: **Biosphäre Potsdam,**
Georg-Hermann-Allee 99, 14469 Potsdam

Abstracts

Tu.1.A | KEYNOTE PRESENTATIONS

Tu.1.A.1 10:15

Adding value to bridges by monitoring and UHPFRC technology

E. Brühwiler [1]
[1] *Swiss Federal Institute of Technology EPFL, Lausanne, Switzerland*

Novel structural engineering methods and technologies are urgently needed to improve the performance of existing structures, such as bridges. Limited funding and ever increasing user demands challenge current technologies which are often invasive and not cost-effective. The objective of this lecture is to demonstrate how novel engineering methods and technologies provide a next long service duration to existing bridges.
At first, the basic approach consists in an accurate determination of in-situ structural behaviour for the structural and fatigue safety verification of bridges using data from in-situ long term structural monitoring of actual traffic action effects. If interventions are necessary, a targeted use of advanced high-performance materials is suggested to improve effectively structural behaviour and resistance. A novel technology is presented to enhance bridges using Ultra-High Performance Fibre Reinforced Cementitious Composites (UHPFRC), a technology applied in Switzerland for more than 10 years. The lecture will be illustrated by application cases including bridges of high aesthetic and cultural value.

Tu.1.A.2 10:50

Potential of the Deformation Area Difference (DAD)-Method for Condition Assessment of Bridge Structures

D. Waldmann-Diederich [1], *D. Erdenebat* [1]
[1] *University of Luxembourg, Esch-sur-Alzette, Luxembourg*

The construction industry ranks in the back rows in terms of digitalization. The numerous existing bridge structures require considerable effort for inspection and reliable assessment of their condition. However, the state-of-the-art for inspecting these structures still relies on the visual inspection realized by bridge inspectors. The current paper summarizes several research projects in the field of condition assessment of bridge structures at the University of Luxembourg by analysing the structural response due to dynamic excitation and static loading tests.
The latest development aims at using the most modern measurement techniques by combining them to a new method, the Deformation Area Difference (DAD)-Method in order to simplify and automatize at most the inspection process. The proposed DAD-Method is based on conventional static load deflection tests. It allows the localization of stiffness-reducing damage by using a very precise measurement of the deflection line and by combining this outcome to the deflection line generated by a simplified finite element model of the bridge. In order to investigate the condition of a bridge by the DAD-Method modern measurement techniques such as photogrammetry and laser scanning are used. In the framework of the conducted research, these techniques are also compared to traditional measurement systems such as total station and inductive displacement sensors as well as to digital levelling sensors. By theoretical examples and experimental tests, it can be shown that the DAD-Method is able to detect and localize damage when the damage level is dominant on the measurement noise.
This paper investigates also the application of the method on a real bridge structure in Luxembourg. All of the above-mentioned measurement techniques were used, whereby the photogrammetry is applied using both, stable tripods and an autonomous flying drone. This allows examining the accuracy of the different measurement systems when applied on a real-size structure.

Tu.2.A | SHM BETWEEN RESEARCH AND APPLICATION: NEW CONCEPTS FOR NEW TECHNOLOGIES

Tu.2.A.1 13:00

Structural health monitoring of the Kurpsai dam – in the Kyrgyz Republic

M. Pilz [1], *K. Fleming* [1], *T. Boxberger* [1], *S. Orunbaev* [2]
[1] *GFZ – German Research Center for Geosciences, Potsdam, Germany;*
[2] *Central Asian Institute for Applied Geosciences, Bishkek, Kyrgyzstan*

Plans to construct hydroelectric dams in the Kyrgyz Republic and the need to assess the state of existing structures, especially with respect to earthquakes and landslides, requires structural monitoring systems that provide rapid and relevant information to decision makers in the event of emergencies. The BMBF-funded project MI-DAM (Multi-parameter monitoring and risk assessment of hydro-electric dams in the Kyrgyz Republic) aims to develop, install and test a robust, cost-effective and flexible structural health monitoring system (SHM) for the Kurpsai Hydropower Station (HPS) in Kyrgyzstan, which will include a multi-parameter risk assessment.
The concept of SHM on the Kurpsai dam in the MI-DAM project distinguishes between two time scales: the long-term monitoring of static deformations over days, months and years and the short-term monitoring of structural response to earthquake shocks and extreme operational regimes. While the long-term monitoring includes a combination of measurements of absolute static displacements by GPS sensors and by fibre optical strain sensors as well as long-term deformations measured by Interferometric Synthetic Aperture Radar (InSAR), the short-term changes in the dam and the surrounding hillsides are monitored by means of multi-parameter sensors placed at selected characteristic points on the structure and surroundings based on a fully decentralised approach. Such an approach allows the critical parameters for monitoring (and, correspondingly, the fragility curves) to be directly integrated into the on-site calculations, allowing some degree of decision-making without the necessity of a remote centre. Strong motion recordings show that the dam exhibits a transient non-stationary behaviour as its fundamental frequency changes during each strong motion, then returning to the starting value after each event. Lapse time coherency allows for the monitoring of spatial changes in the phase of ground motion, indicating the opening/closing at the joints and lateral excitation. Moreover, the continuous recording of seismic noise, i. e., the persistent vibration of the ground due to a multitude of natural and anthropogenic causes, allows for the continuous assessment of the mechanical characteristics of a dam (and hence, fragility curves) and any changes therein.

Tu.2.A.2 13:15

Satellite Based Longterm Deformation Monitoring on Dams and its Surroundings

O. Lang [1], D. Walter [1], J. Anderssohn [1]
[1] Airbus Defence and Space, Potsdam, Germany

Introduction: Surface deformation of dams and its surroundings may endanger infrastructure and even human lives. Satellites monitor single structure displacements and movements of surrounding landscapes at regular intervals. They can help to understand the nature of ground instabilities and formulate an adequate response. Satellite based monitoring ideally complements terrestrial surveying.
Methods: InSAR (Interferometric Synthetic Aperture Radar) is a technique that allows mapping millimeter-scale deformations of the earths surface with radar satellite measurements in a very high resolution. In general the precision of InSAR movement measurement is optimized by interferometric time series analyses with an increasing stack of radar acquisitions over time. A precision within the range of few milimeters will then be achievable for each individual measurement. Thousands or even millions of measurement points can be reliably analysed. Results Detailed movement maps for dams in Kirgizstan and Iraq are created, demonstrating the capacity of the InSAR technique. The Mosul dam in Iraq is well known for standing on unstable soft soil and gypsum. The results show surface movements that may arise from underground instabilities and water pressure of the reservoir.
Conclusions and Contributions: The presented results demonstrate that satellite based interferometric monitoring provides precise and cost-effective information suitable for static risk assessment approaches.

Tu.2.A.3 13:30

Structural Health Monitoring (SHM) of transport infrastructure – challenges, solutions, trends

J. Kuehne [1]
[1] Wölfel Engineering GmbH + Co. KG, Höchberg, Germany

Measurements on bridges can be required by various reasons. For example, short-term measurements are needed to validate designs; longer measurements often take place during operation of temporary bridges or to monitor different construction states. Long-term measurements (SHM) with recording of impacts and structural reactions support inspections or build a basis for predictive asset management.
The major challenge in maintaining the existing bridges consists in assessing the structural constitution, identifying critical conditions, deriving suitable actions and allocating the necessary funds quickly and efficiently.
Permanent monitoring of structures using intelligent sensor systems capable of providing objective, reliable and comparable information in real time has many advantages:
- Increased safety
- Additional availability
- Demand-oriented allocation of funds
- Additional information

The presentation takes up some projects, compares challenges and opportunities of different approaches and names future fields of action for an efficient implementation of SHM in the market.
Based on the political framework, mainly technical, but also legal and economic aspects of the topic will be highlighted:
- Requirements for the use of measurement technology
- Sensor technology and data acquisition
- Data management - Data analysis
- Data security
- Contract law
- Proof of economic efficiency

Tu.2.A.4 13:45

Safety equivalent assessment of bridges considering structural monitoring

N. Steffens [1], K. Geißler [1]
[1] TU Berlin, Germany

Due to the large number of old bridges as well as the increase of traffic loads – especially by road bridges – the realistic assessment of existing structures becomes more important. Existing structures are characterized by the possibility of obtaining additional information about actual stresses and their load capacity. Therefore, structural measurements (or monitoring if performed over a longer period) are being used increasingly to assess the condition of existing bridges in a more realistic way. Meanwhile, the possibilities of using structural measurements or monitoring are versatile and the technical conditions for a safe implementation are given. However, it still must be clarified, to which extent the additional information obtained by structural monitoring are to be taken into account within the structural safety concept.
This paper describes how to integrate more detailed, measurement-based information about actual stresses into the safety concept of assessment of existing bridges. This concerns ultimate limit state with recording extreme values as well as fatigue limit state with recording loading spectrums. The introduced method of safety equivalent assessment includes three modules.
In the first module the general assessment of existing structures can be done using limit state functions considering measured stresses. Because of the model uncertainty in the fatigue limit state e. g. concerning the damage accumulation hypothesis the limit state function of fatigue should be used with caution. In the second module simplifying methods can be used to determine measurement-based safety factors as well as load models for time-dependent loads for ultimate limit state and fatigue limit state. The third module includes additional issues such as combination factors of temperature.
With this systematical method a direct contribution can be given for solving the current and socially relevant problem of the realistic assessment of bridges.

Tu.2.A.5 14:00

Long-term SHM system for a concrete gravity dam

Y. Petryna [1], P. Kähler [1], W. Elsesser [1]
[1] TU Berlin, Germany

The present contribution deals with the concrete gravity dam at the Kurpsai Hydropower station in Kyrgyz Republic situated in a seismic

area. An international consortium is developing a new continuous structural health monitoring system for the dam within the MI-DAM project, funded by the German Ministry of Education and Research (BMBF).
The focus of this contribution lies on the application of various long-term deformation measurement techniques to assess the current state of the dam over the entire service life. It includes the GNSS sensors, the InSAR measurements and the fiber-optical sensors. The measured deformations are used in the global 3D finite element model of the dam and surrounding hillsides to predict stresses under environment influences like temperature and soil settlements. The FE model is validated by use of the dynamic and static measurements. The developed SHM system is installed in May of 2018. Some typical results and challenges will be presented and discussed during the conference.

Tu.2.A.6 14:15

Local and global state parameter extraction from ambient vibration measurements on bridges

P. Kähler[1], Y. Petryna[1]
[1] TU Berlin, Germany

Structural health monitoring of bridges is a topic of research and development since long. Impressive progress has been achieved in the last decades, especially due to a rapid development of measurement and communication techniques as well as that of new theoretical methods. Some tasks like operational modal analysis OMA can already be solved very efficiently and reliably. Some others like local damage detection and localization are still a challenge both for research and application.
The present contribution is dedicated to some new techniques for structural health monitoring and its application to bridges. One method under consideration is based on the Hilbert-Huang Transform (HHT) which exhibits a good potential for the extraction of state parameters from vibration measurements under operation conditions. For example, the vibration decay after a track passage can be used to extract important information on the bridge condition. The Hilbert transform combined with the Empirical Mode Decomposition by Huang allows the identification of the instantaneous vibration frequencies, phases and damping ratios for individual vibrations modes as well as their nonlinear changes due to the vibration amplitude and damage. The damping and nonlinear effects are known to be more sensitive to local damage than the fundamental frequencies. The monitoring of the same short-term parameters after each track passage enables to develop a long-term monitoring strategy by use of regular time intervals in hours, days, weeks, months and years. By variation of the sensor location it is also possible to localize damage by use of HHT.
This contribution shows the application of the presented monitoring technique to a road bridge and a foot bridge in Berlin.

Tu.2.A.7 14:30

Seismic screening approaches for detection of structural changes

C.-M. Liao[1], Y. Petryna[1]
[1] TU Berlin, Germany

The present contribution is dealing with seismic screening of buildings by use of seismic interferometry and wave deconvolution analysis. At that, the artificial wave propagation between two sensor positions is reconstructed from the ambient vibration measurements. The wave propagation velocity within a sensor network can be used to estimate structural stiffness, locally and globally, i. e. depending on the sensor position. The change of the wave characteristics are assumed to be caused by the stiffness change due to damage. This approach is studied on a 14-story building in Bishkek, Kyrgyzstan and a foot bridge in Berlin, Germany. It is compared to a classical operational and numerical modal analysis. Alternatively, the application of the so-called transmissibility functions for damage detection is explained and illustrated. The transmissibility functions can be determined from the ambient vibration measurements of the same kind as used for the wave propagation analysis. A comparison of the both mentioned approaches to seismic screening is currently in progress.

Tu.2.A.8 14:45

Bridge Remote Sensing Using TerraSAR-X Satellite

E. Hoppe[1], F. Novali[2], A. Rucci[2], A. Fumagalli[2], S. Del Conte[3], G. Falorni[3], N. Toro[3]
[1] Virginia Department of Transportation, Charlottesville, USA; [2] TRE ALTAMIRA s.r.l, Milano, Italy; [3] TRE ALTAMIRA Inc., Vancouver, Canada

Routine safety inspections performed at two post-tensioned bridges in Virginia revealed extensive cracking in the concrete girders. Subsequent tests indicated widespread problems traced to the inadequate quality of tendon grouting, resulting in a partially bonded condition. Interferometric Synthetic Aperture Radar (InSAR) technology was applied to monitor bridge displacements over time. The TerraSAR-X radar satellite, orbiting at 515 km above the Earth, acquired data at 11-day intervals over a period of 16 months. The data were processed with the SqueeSAR algorithm, resulting in the millimeter range precision of time-displacement series. SqueeSAR analyses performed on the TerraSAR-X Staring Spotlight data provided an exceptionally high density of measurement points within the area of interest, including very comprehensive coverage of both bridges. There were 1,228,464 distinct points with associated time series of displacements identified from the ascending geometry and 1,025,768 points obtained from the descending orbit. The resulting point density per square kilometer was 164,233 and 137,134 for the ascending and descending tracks, respectively. The results indicate that implementing a viable bridge performance monitoring program through the use of satellite remote sensing is feasible.

Tu.2.B | SHAPE MEMORY ALLOYS (SMAS) FOR ENGINEERING APPLICATIONS (I)

Tu.2.B.1 13:00

An overview of research on SMAs with a focus on seismic risk mitigation

H.H. Aydoğdu[1], A. Ilki[1]
[1] Istanbul Technical University, Istanbul, Turkey

Shape Memory Alloys (SMAs) are smart materials that have plenty of distinctive features. Having huge damping capability, combined with

good corrosion resistance, and ability to recover their original shape up to 8% strain by heating the material or removing the stress, SMAs have been widely investigated for civil engineering applications in last decades. Owing to its high fatigue resistance and re-centering capacity under repetitive cyclic loading, SMA devices or reinforcements can perform well during and after multiple strong seismic excitations without causing any significant residual drifts in the structure. In this paper, after an overview of unique properties of SMAs such as shape memory effect and superelasticity, recent research on the use of SMAs in terms of seismic risk mitigation such as braces, retrofitting systems, dampers, restrainers, isolation systems and reinforcement are discussed in a comparative manner. Then the benefit of using SMAs as a part of diagonal braces in a substructure system has been demonstrated by numerical modelling and nonlinear time history analyses of these structural systems.

Tu.2.B.2 13:15

STRUCTURAL CONCRETE STRENGTHENING with Fe-SMA STRIPS: CASE STUDY with specific CONTROL AFTER ACTIVATION

J. Mercier[1], B. Basile[1], X. Hallopeau[1], J. Michels[2], C. Tourneur[1]
[1] FREYSSINET International & Cie Département Technique, Rueil-Malmaison, France; [2] Re-fer AG, Brunnen, Switzerland

This paper presents the application of a novel prestressing technique by means of iron-based shape memory alloy (Fe-SMA) strips. This innovative material has the ability to regain its initial shape upon heating, after having initially been permanently prestrained at ambient temperature. Without any free movement caused for instance by an end-anchorage, a prestress develops in the material. In our case, the alloy is in form of 1.5 mm thick and 100mm wide plates, end-anchored with specific nails at each extremity. An application of externally applied, end-anchored and unbonded Fe-SMA strips was realized in a school building in France in 2017. The installation of three Fe-SMA strips was performed in order to obtain a crack closure in a reinforced concrete slabs. It was demonstrated the easy process of installation with no surface preparation, applying of anchorages and relative moderate power machines for activation of laminates. Measurements with Omega-gauges over the crack demonstrated the efficiency of the prestressing.
In addition to the temperature measurements, a specific crossbow technique was developed and used to assess the prestressing force in the Fe-SMA strip just after the operation and also 1 year later. Easy to use and to analyse, it allowed to confirm the exact stress induced after the activation process. It was also demonstrated the good comportment in time and reduced relaxation after this long term period.

Tu.2.B.3 13:30

Effectiveness of NiTi-SMA Bars at the Beam Column Joint Interface

M. Rahman[1], M. Al-Huri[1], A. Al-Gadhib[1], M. Baluch[1], M. Alosta[1]
[1] King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia

Seismic detaining of BCJs in Codes require the incorporation of shear reinforcement in the joints to enhance their shear capacity. The mode of failure in seismically detailed joints precludes the brittle shear failure of joints and promotes a ductile failure in beams, with flexural cracking generally occurring at the BCJ interface. The functionality of such joints may also be compromised due to the yield zone at the interface penetrating into the joint. Shape memory alloy (SMA), is a functional material that exhibits small residual strain under loading and unloading cycles even after yielding of the material, in sharp contrast to the normal steel. It can undergo large deformations and return to its undeformed shape on the removal of the stress. SMA in the form of bars, can be used at the beam column joint interface. These bars can yield under the strains caused by seismic loads but potentially recover deformations after the end of the event. Only few researches have been directed towards understanding the ability of SMAs to recover deformations and decrease residual deformations in concrete structural elements. Therefore, SMAs used as embedded rebar, might have a good potential to be used in seismic zones in RC structures, especially at the BCJs in new structures. BCJ specimens reinforced with 12 mm dia SMA bars in the plastic hinge region were tested under monotonic, cyclic and reverse cyclic loading. Experimental investigation of BCJs reinforced with trained and both ribbed and plain SMA bars shows excellent results in terms of crack recovery, residual displacement, and load capacity.

Tu.2.B.4 13:45

Behavior of iron-based shape memory alloys under cyclic loading histories

D. Isidoro Heredia Rosa[1], A. Hartloper[1], A. Sousa[1], D. Lignos[1], M. Motavalli[2], E. Ghafoori[2]
[1] Ecole Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland; [2] Empa, Dübendorf, Switzerland

Shape memory alloys (SMAs) have gained considerable attention in a broad range of applications including the strengthening of civil infrastructure. These alloys exhibit superelasticity and shape memory effect (SME), which results from the recovery of a large stress-induced strain in a SME to its original shape when the SMA is subjected to heating. Iron-based SMAs (Fe-SMAs) provide a cost-effective alternative to Ni-Ti SMAs. However, the potential use of Fe-SMAs in seismic design and retrofit applications including supplemental damping requires the further understanding of the material behavior under cyclic loading. This paper discusses key findings from a material-level experimental program that involved Fe-SMA round coupons subjected to a broad range of uniaxial cyclic strain histories representative of earthquake loading. The loading histories manifest the Fe-SMA material properties associated with its nonlinear behavior including the Bauschingher effect and the cyclic hardening. A comparison with typical mild steels undergoing the same loading histories is also discussed.

Tu.2.B.5 14:00

Shear strengthening using external Fe-SMA strips

L.A. Montoya-Coronado[1], J.G. Ruiz-Pinilla[1], C. Ribas[1], A. Cladera[1]
[1] University of Balearic Islands, Palma (Balearic Islands), Spain

New Fe-based shape memory alloys (Fe-SMA) have been developed during last years, and on-going research shows that they may become a competitive material for civil engineering applications due to their low cost in comparison to other shape memory alloys, their mechanical properties and corrosion resistance. The main highlighted property of the used Fe-SMA is the ability to recover around 1% of its shape by heating it up to 160°C after being previously deformed. More importantly, bars and strips made of Fe-SMA can be used to

prestress concrete members if the free recovery of the SMA element is restrained, obtaining recovery stresses upon 350 MPa. In this communication, a comprehensive characterization of a commercially available Fe-SMA strip will be presented. The Fe-SMA strips have been used to externally retrofit small scale beams without shear reinforcement. The paper will present the different behavior of the reference beams (without shear reinforcement), the retrofitted beams (with the activated strips fully wrapping the beams, generating recovery stresses) and with beams with the externally placed strips but without activation. The retrofitted beams with activated strips failed on bending, with a clear delay of the apparition of the shear cracks, meanwhile the reference beams failed on shear.

Tu.2.B.6 14:15

3-D Non Linear Finite Element Modeling of Exterior R.C Beam-Column Joint Partially Reinforced With Shape Memory Alloys (SMAs) and Existing of Transverse Beam

A. Halahla [1], Y. Abu Tahnat [2]
[1] Fahad Bin Sultan University, Tabuk, Saudi Arabia; [2] Middle East Technical University, Ankara, Turkey

The beam-column joint (BCJ) in reinforced concrete construction is considered to be the crucial zone in the reinforced concrete frame, as it is the critical element subjected to a complex state of forces during severe ground shaking. Its behavior has a significant influence on the response of the structure, namely with reference to its ductility and energy dissipating capability. This research focuses on studying the effect of using superelastic shape memory alloy (SMA), and a transverse beam (secondary beam) on the ductility of exterior reinforced concrete beam-column joints. Some of parameters controlling the ductility of joints are studied. Finite element analysis using ABAQUS is used to investigate the ductility behavior of exterior reinforced concrete joints. SMA is considered one of the methods to improve the ductility of exterior reinforced concrete joints at the plastic hinge zone, in this paper, SMAs with super-elastic effect are referred to as Nitinol SMAs is used which composition are Nickel-Titanium alloys (55.9% Ni and 44.1% Ti). In addition to add transverse beam. In this reasearch, the beam-column joint has a concrete compressive strength of 21 MPa. The concrete damage plasticity model (CDP) is used for concrete , while the bilinear model is used for steel. On the other hand, the real behavior of SMA, as studied in the literature review, is used for the modeling of SMA. In order to validate the model, numerical analysis is compared with the experimental work. The result showed that both SMA and the tranverse beam enhance the ductility of the joint effectively.

Tu.2.B.7 14:30

Long-term behavior of reinforced concrete beams strengthened by iron-based shape memory alloy strips

M. Shahverdi [1,2], C. Czaderski [1]
[1] Empa, Dübendorf, Switzerland; [2] University of Tehran, Iran

During the last two decades, low cost Fe-Mn-Si based shape memory alloys have attracted much attention in the research community and practice, as a cost-effective alternative to the expensive Ni-Ti based shape memory alloys. A shape memory alloy (SMA) has the unique property to remember its initially given shape after being deformed. The reason is that its crystal transformation is reversible. Empa and Company re-fer developed an iron based shape memory alloy (Fe-SMA), also denominated as memory-steel. The Fe-SMA can be used as near surface mounted NSM strengthening reinforcement. The NSM Fe-SMAs can more easily be prestressed than NSM FRP, because prestressing of SMAs does not require any mechanical jacks and anchor heads. This practice requires cutting grooves in the cover of the concrete and no surface preparation work is needed afterwards. When NSM Fe-SMAs are used for the strengthening of concrete structure, one critical aspect that needs to be investigated is the long-term behavior of such applications. The current paper presents an experimental investigation to determine the long-term behavior of strengthened RC beams under sustained loading in an outdoor exposure environment using an older prototype of Fe-SMA elements. Two beams strengthened with NSM ripped Fe-SMA strips, one with activated Fe-SMA strips and one with not-activated Fe-SMA strips, have been loaded until more than their cracking loads and their behavior have been monitored for about four years. Results show that both beams have similar trends in their mid-span deflection measurements, what indicates a stable prestressing force in the Fe-SMA strips.

Tu.2.B.8 14:45

Fire Behavior of Prestressed Iron-Based Shape Memory Alloy (Fe-SMA)

E. Ghafoori [1], M. Neuenschwander [2], M. Shahverdi [1], C. Czaderski [1], M. Fontana [3]
[1] Empa, Dübendorf, Switzerland; [2] University of California Berkeley, Pacific Earthquake Engineering Research Center, Berkeley, USA; [3] ETH Zurich, Switzerland

Iron-based shape memory alloy (Fe-SMA) members have been recently introduced for prestressed strengthening of civil structures such as buildings and bridges. As civil structures are often prone to elevated temperatures when exposed to fire, the high-temperature behavior of the structural elements including all the materials used for rehabilitation is of great importance. Therefore, this study provides the first systematic study on the structural fire behavior of the prestressed Fe-SMA members. A series of transient total deformation tests was conducted on Fe-SMA strips with two thicknesses of 0.5 and 1.5 mm. The Fe-SMA strips were first activated and then prestressed. The transient tests were then performed for service loads of 0, 80 and 240 N/mm2 and heating rates of 5, 15 and 50 °C/min. From the transient total deformation tests, the mean high-temperature creep onset-temperatures and failure temperatures of the 1.5 mm and 0.5 mm specimens were approximately 527 and 598 °C and 517 and 596 °C, respectively. For all different service load levels and heating rates examined, a high-temperature creep onset-temperature greater than 500 °C was observed, and the corresponding failure temperatures exceeded the latter by approximately 50-70 °C.

Tu.2.C | DAMAGE CONTROL, REPAIR AND STRENGTHENING (I)

Tu.2.C.1 13:00

Bond performance at elevated temperatures of near surface mounted CFRP laminates using cement-based adhesives

R. Mohammadi Firouz [1], E. Pereira [1], J. Barros [1]
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Carbon fiber reinforced polymer (CFRP) systems are being used extensively in construction industry, especially in the strengthening of reinforced concrete (RC) structures due to their advantages over conventional materials, mainly in terms of upgrading the load carrying capacity with minimum increase of dead weight and geometric alterations to the strengthened elements. This is especially notable when using the near surface mounted (NSM) technique, since CFRP reinforcements are installed into thin grooves executed in the concrete cover of the RC elements to be strengthened. The CFRP reinforcement elements are bonded to the concrete substrate by using, in general, polymer based materials, such epoxies. Despite their notable mechanical and durability performance in natural environmental conditions, when submitted to high temperatures the properties of these polymer based adhesives are detrimentally affected, in a level that can compromise the strengthening effectiveness.
Hence, it is of a great importance that in such cases, alternative adhesives can be used in order to maintain the target strengthening level, even when high temperatures are reached, such as the ones representative of a fire. The incombustibility and low thermal diffusivity of cement-based materials make them a potential alternative for bonding CFRP reinforcements according to the NSM technique, mainly when relatively deep grooves can be executed for the installation of these reinforcements.
Recent research has demonstrated that utilizing cementitious matrices as adhesives in FRP systems can constitute a proper medium for the transfer of stresses between these systems and the concrete substrate. However, the performance of these cement-based adhesive in high temperature conditions was not yet explored in a comprehensive way. The present work aims to contribute for this topic, by developing a cement-based adhesive and assessing its potentialities as a bond agent for the concrete structures strengthened according to the NSM technique while subjected to high temperatures, by performing experimental tests and numerical simulations considering the NSM characteristics. Test results signify the effectiveness of the new adhesives under high temperature in maintaining considerable amount of residual bond strength.

Tu.2.C.2 13:15

Innovative nanostructured materials as cold-cured adhesive/matrix of FRP for strengthening of building structures

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Thermosetting cold-cured resins are largely used as structural adhesives and/or matrix to manufacture and apply fiber reinforced polymers (FRP) composites employed in retrofitting technique. The slow development of their mechanical, adhesive and physical properties due to a cold-cure process represents a serious inconvenience in the repair procedures of large structures. Furthermore, the durability of these materials is still unclear, especially when they are outdoor exposed to common or harsh environmental conditions. These issues are likely to hamper the enormous potential of structural adhesives in construction field and their composites employed for stregthening and rehabilitation of infrastructures. The development of innovative nano-materials based on thermosetting (mainly epoxy) resins to be used as matrices/adhesives for FRP composites has been recently explored in the view to overcome some of the well known drawbacks of traditional structural adhesives and matrices for construction industry. Some of the recent findings in this field will be illustrated.

Tu.2.C.3 13:30

Lifetime prediction of flax fibre reinforced composites

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Flax fibre reinforced composites are demonstrating promising outcomes which makes them potential candidates to replace synthetic composites in various industrial applications. However there is limited information regarding their long-term performance. It is widely acknowledged that natural fibres are less resistant than their synthetic counterparts, so it is crucial to study their durability before considering their use for real applications in rehabilitation and strengthening of structures. For the above reasons, this study, lying within the framework of the National Research Agency project MICRO, aims to study and predict the performance of flax fibre reinforced composites with a bio-based epoxy matrix. This is achieved by exposing the bio-composite and samples made of bio-composite bonded on concrete slabs to different accelerated ageing conditions over a total period of 2 years, and with various combinations of temperature and relative humidity in the ranges 20°C-60°C and 50%-100% RH, respectively. Then a series of tensile, short beam and pull-out tests are performed periodically on the ageing samples. Finally, the collected experimental data are analyzed using a reliability method in order to evaluate the service lifetime performance of this new bio-based composite.

Tu.2.C.4 13:45

Influence of UHPC laminate application type on fracture behavior of reinforced concrete beams strengthened in flexure

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Ultra High Performance Concrete (UHPC) is a cement-based composite which attracts the researchers interest due to its superior mechanical and durability properties. It has high strength and energy absorption capacity under bending loads. Because of these properties, UHPC has also been involved in strengthening procedures. Acoustic emission (AE) is one of developed nondestructive testing methods giving integrated information about active fractures. It is also proper for identifying failure mechanisms of UHPC. In this study, influences of application type of UHPC laminate on fracture behavior of reinforced concrete (RC) beams under flexure were investigated. For this purpose, three RC beams were produced and two of them

were strengthened with UHPC laminates. While UHPC laminate of one of strengthened beams was attached with epoxy, the other was anchoraged. The beams were tested under four-point-bending and simultaneously monitored with AE. Both mechanical and AE results show that fracture behaviors change with application type.

Tu.2.C.5 14:00

Fatigue Performance of FRCM Strengthened RC Beams Subjected to Varied Fatigue Frequencies and Environmental Exposure

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Progressive and localized structural damage occurs when materials are exposed to oscillated loads at a certain stress limit. This is the case for reinforced concrete beams in bridge applications. This study focused on the fatigue performance of a fiber reinforced cementitious matrix (FRCM) composite used to repair reinforced concrete beams to determine its capability in relative to fatigue and environmental exposure in bridge rehabilitations. Specifically, this paper examined the effect of different environmental exposure and fatigue frequency on the strengthened beams stiffness performance. A monotonic flexural test followed two million successful cycles of fatigue loading. The capability of a FRCM composite in resisting fatigue loadings under severe environmental conditioning were also determined. Beam stiffness degradation ranged between 12% and 23% based on the exposure conditions, the FRCM reinforcement ratio, the fatigue frequency, and the concrete strength. The FRCM system yielded positive overall fatigue resilience even when exposed to severe conditioning.

Tu.2.D | NON-DESTRUCTIVE TESTING IN CIVIL ENGINEERING (I)

Tu.2.D.1 13:00

Review of recent developments in ultrasonic echo testing of concrete

E. Niederleithinger [1], S. Maack [1], F. Mielentz [1], U. Effner [1], C. Strangfeld [1]
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Ultrasonic methods are used in concrete investigations since decades. While being limited to transmission testing in the laboratory for a while, in-situ echo measurements for structural investigations and condition assessment have made their way into practical application in the past 20 years. However, several challenges remain. On one side, there are technical issues as limitations in depth of penetration, resolution and imaging capabilities. On the other side there are still gaps in validation, standardization and certification, which are limiting the applicability in condition assessment and capacity calculation schemes. This review reports a couple of developments which will help to overcome these issues. This includes technical developments as new devices which are easier to handle on site or giving a much deeper penetration depth (e.g. the LAUS device at BAM) as well as improvements in imaging by hardware update (e. g. air coupled ultrasound or coded signals) or new software (e. g. RTM imaging). To foster the application in real world project we are as well working on standardization by developing new reference specimen with international partners which will ensure world-wide comparability of ultrasonic and other methods, quality assurance codes and inclusion of non-destructive methods in updated probabilistic model codes.

Tu.2.D.2 13:15

Characterization of Moisture Transport Properties of Cement-based Materials using Electrical Capacitance Tomography

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Water, and aggressive agents transported with it are the main factors that speed up deterioration processes in concrete structures. Thus, information on moisture transport properties would be valuable when assessing or predicting the material durability. Traditional techniques to monitor water ingress inside cementitious materials are based on weighting or slicing the specimen. Neither of these methods provide complete information of the moisture transport if the moisture is three-dimensionally distributed, and moreover, the slicing method is destructive. Advanced techniques to monitor the water movement include neutron imaging, magnetic resonance imaging, X-ray and electrical resistance tomography (ERT). However, these methods have limitations; for example, many of them are too expensive for operational use and are limited to small specimens and laboratory environment only. While ERT may not suffer from the above limitations, it is suitable only for imaging surface wet (electrically conductive) specimens.
Our recent studies have shown that in surface-dry cement-based materials, a suitable technique to monitor moisture ingress is Electrical Capacitance Tomography (ECT), which is based on imaging the electrical permittivity distribution on the basis of capacitance measurements from the surface of the object. In this work, we apply ECT for imaging 3D moisture flows in mortar specimens with different water-to-cement ratios. The primary goal of the experiments was to demonstrate the capability of ECT to visualize the movement of water inside cement-based materials in 3D. Secondly, we studied whether the ECT reconstructions could be further used for estimating material parameters experimentally. For the latter aim, we combined the information provided by ECT with a moisture flow model, and estimated the saturated hydraulic conductivities of mortars. The results show that ECT can image 3D moisture flows within mortar specimens with a good accuracy when compared to numerical moisture flow simulations. Moreover, the estimated hydraulic conductivities of different materials were in good correspondence with the values determined with separate absorption tests.

Tu.2.D.3 13:30

Comprehensive Full-Depth Evaluation of Concrete Bridge Decks Based on GPR Surveys and Machine Learning

A. Imani [1], S. Saadati [1], N. Gucunski [1]
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The traditional practice for condition evaluation of concrete bridge decks using GPR is limited to the condition of the deck above the top reinforcement mat without providing any useful information about the state of concrete below. In an attempt to expand the GPR evalua-

tion zone beyond the top rebar, this study examines a machine learning algorithm as an alternative to the traditional GPR data analysis. Gradient boosting was used to analyze a dataset compiled through GPR surveys of four concrete bridge decks in the United States and to costruct a learning algorithm for the purpose of analyzing other experimental GPR data. Two independent prediction modules were developed: Module 1 to predict the condition above the top rebars, and Module 2 to predict the condition of concrete in between the top and bottom rebars. A validation test slab in the laboratory was surveyed using the same GPR system, and the data were used to validate the algorithm. The implementation of the proposed method in the validation phase showed that using machine learning and a vast library of GPR data, it is possible to avoid the subjective 90th percentile depth correction for new bridges without compromising the ability to assess the deck condition accurately.

Tu.2.D.4 13:45

Towards predictor development for assessing structural integrity of components made from wood materials using Acoustic Emission monitoring and signal analysis

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Against the background of sustainable resource management and efficiency, wood-based materials are currently experiencing a revival and, among others, plywood, Laminated Veneer Lumber and glued laminated timber are becoming increasingly more important in the building sector. Even though these materials are so-called engineered products, the element wood is naturally grown with intrinsic variability in mechanical properties and requires professional handling on-site. Otherwise, load-bearing structures made of wood materials may entail certain risks. Critical situations can, in principle, be avoided by implementing a structural health monitoring system into components or structures made from wood material. The aim of this is to indicate accumulation of mechanical damage and to eliminate or at least significantly reduce the risk of unexpected failure. Toward this purpose, the failure behavior of several layered wood materials under quasi-static tension was investigated in laboratory-scale experiments by means of acoustic emission (AE) measurement. Based on spectral analysis and pattern recognition, two classes of AE signals are identified for each investigated lay-up that are characterized by either low or high frequency contents in the respective power spectra. AE activity and intensity of both signal classes are analyzed, striving for predictors appropriate for acoustic emission monitoring concepts.

Tu.2.D.5 14:00

Machine learning based multi-sensor fusion for the nondestructive testing of corrosion in concrete

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Half-cell potential mapping (HP) is the most popular non-destructive testing method (NDT) for locating corrosion damage in concrete. It is generally accepted that HP is susceptible to environmental factors caused by salt-related deterioration, such as different moisture and chloride gradients. Additional NDT methods are able to identify distinctive areas, but are not yet used to estimate more accurate test results. We present a Supervised Machine Learning (SML) based approach to data fusion of seven different signal features to obtain higher quality information. SMLs are methods that explore (or learn) relationships between different (sensor) data from predefined data labels. In order to obtain a representative, labelled data set we conducted a comprehensive experiment simulating the deterioration cycle of a chloride exposed device in the laboratory. Our data set consists of 18 measurement campaigns, each containing HP, Ground Penetrating- Radar, Microwave Moisture and Wenner resistivity data. We compare the performance of different ML approaches. Many outperform the best single method, HP. We describe the intrinsic challenges posed by a data-driven approach in NDT and show how future work can help overcome them.

Tu.2.D.6 14:15

Super-resolution images for measuring structural response

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Obtaining reliable and precise response measurements of structures subjected to loading is important, especially when assessing their conditions and deriving load-response relationship. A range of contact sensors can collect both structural response and applied loads. When considering beam structures such as girder bridges a control load (a truck of a known weight) can be applied and response can be measured. Developments in digital cameras and image processing enable collection of structural deformations using vision-based technologies, which do not require access to the structure, are non-destructive and low cost. Measurement accuracy largely depends on the image resolution and processing algorithm. When capturing an entire structure in a single image frame, it is unlikely that structural response at multiple locations can be measured accurately. This study proposes to create super-resolution images by stitching high-resolution images, from which accurate structural response is obtained. A robotic camera which is programmed to capture images and rotate along its vertical axis is developed. Initially the accuracy of image stitching is investigated using laboratory beam. The robotic camera captures images at different distances to the structure and zooms. Deformations of a laboratory beam subjected to static loading are then obtained using the robotic camera, smartphone and contact sensors. The results show that the accuracy of measurements collected with the robotic camera system is in a good agreement with the contact sensors and much higher than those obtained with a smartphone camera.

Tu.2.D.7 14:30

Acoustic emission and ultrasonic testing for fatigue damage detection in a RC bridge deck slab

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There is a significant need to examine precisely the conditions of concrete road bridges because of the increasing traffic and axle loads and the fact that most existing bridges were not designed with respect to fatigue. In-situ investigations are challenging in terms of long-term monitoring of deformations and displacements, the diffi-

culty of access to relevant zones of bridges in service, and limitations in current measurement methods and techniques.
This paper presents the case study of a specifically designed continuous monitoring system, installed in the reinforced-concrete slab of a 60-year road viaduct, in order to detect possible initial fatigue damaging events due to traffic loading, since the slab currently does not show any sign of fatigue damage in terms of cracks.
The originality of the paper lies in the combination and synchronization of four non-destructive-testing techniques, i.e. an acoustic emission system, an ultrasonic system, strain gauges, and thermocouples, to perform long-term monitoring of the RC deck slab of this viaduct under service conditions. It is found that the monitoring system is efficient to detect acoustic emission parameters as a function of traffic and temperature variations.

Tu.2.D.8 14:45

The Impact-Echo method applied to the auscultation of bridges: Numerical study

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Impact-Echo is defined as a non-destructive method for the evaluation of concrete and masonry structures, based on the use of impact-generated compressional waves, which propagate through the material and are reflected by internal defects or external surfaces of the structure. This non-destructive method can be used to determine thicknesses and locate defects in concrete and masonry plates. It is a very promising method for the evaluation of concrete and masonry structures, therefore mastering how the method works and knowing how to interpret the results, are primary for a successful test. This method has already been proven to be quite efficient for the evaluation of concrete plates and is still to be developed for masonry structures. While previous studies have mainly focused on detecting and locating defects in single-layer plates , and evaluating the bond quality at internal interfaces in bi-layer ones, the identification of defects located in the second layer of a bi-layer plat has yet to be explored. This paper falls within the framework of the evaluation of masonry bridges, where one of the common problems we encounter is to detect voids and defects located in the fills behind the head walls and vaults. Such pathology may turn out to be quite dangerous. Indeed, the deterioration or loss of materials in this filling can directly or indirectly affect the behavior and safety of the bridge structure. In this study, we will investigate the capabilities of Impact-Echo method to identify defects located in the second layer (the head walls or the vaults being the first layer and the fill being the second one). In a first step, a numerical study is realized by varying different parameters such as the thickness of the first layer, the mechanical parameters of the bi-layer plate and the depth of the defect. In a second step, the results obtained numerically will be confronted with the experimental results obtained from tests carried out in laboratory.

Tu.3.A | SHAPE MEMORY ALLOYS (SMAS) FOR ENGINEERING APPLICATIONS (II)

Tu.3.A.1 15:30

PLENARY LECTURE: Feasibility of Superelastic Large Diameter Copper-Aluminum-Manganese SMA Bars in Bridge Columns

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Superelastic Copper-Aluminum-Manganese (CAM) reinforcing bars present an attractive alternative to steel bars in reinforced concrete structures not only because they provide resistance and ductility under earthquake loads, but they also minimize residual displacements. Reduction in residual displacement when combined with ductile, low damage cementitious materials in critical parts of columns would help keep bridges in service even after strong earthquakes and would make infrastructure resilient. Recent research conducted at the University of Nevada, Reno, USA has already demonstrated improved resiliency of bridge columns utilizing relatively small diameter (15 mm) CAM bars combined with engineered cementitious composites (ECC) through shake table testing of large-scale column models and a two-span bridge model. For efficient use of CAM bars, they are used only in plastic hinges of bridge columns. Therefore, they have to be spliced to steel reinforcing bars outside the plastic hinge. Splicing of CAM and steel bars has to utilize couplers. Two types of couplers have been studied in the UNR studies: standard threaded couplers and headed bar couplers. The former relies on threading the CAM bar ends and reducing the CAM bar section to dog bone shape elsewhere to avoid failure within the threads. Threading and machining of the bars is costly and time consuming. The headed bar coupler splices eliminate the need for threading and machining. It allows for the use of full CAM bar section because no machining to dog bone shape is involved. The headed bar connection was recently utilized in bars with 30-mm. To be implemented in real bridge columns, the bar diameter typically needs to be of this size. The presentation will include the data for each connection testing and bar size and pros and cons of each connection type along with the current and upcoming research on CAM bars.

Tu.3.A.2 15:50

Nailed iron-based shape memory alloy (Fe-SMA) strips for strengthening of steel members

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The paper presents the development of an iron-based shape memory alloy (Fe-SMA) retrofit system with end-nailed mechanical anchorages for strengthening of steel members. In the first step, a series of lap-shear tests was conducted to investigate the performance of different anchorage designs. To this end, a digital image correlation (DIC) system was used to monitor the slip behavior of the anchorage zone. In the second step, the optimized mechanical anchorage was then employed to strengthen a steel girder of 6.4 m in length with a pre-strained Fe-SMA strip that was applied externally. A four-point bending test setup was arranged accordingly. Infrared heating technique was used to heat up the Fe-SMA strip to maximum temper-

ature of 160 °C, resulting in activation and therefore, induction of prestress. Finally, static and fatigue loadings for more than 2.5 million cycles were applied to assess the reliable performance of the proposed nailed Fe-SMA strengthening system.

Tu.3.A.3 16:00

Strengthening of concrete structures with iron-based shape memory alloy elements: Case studies

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The feasibility of new strengthening methods using a novel iron-based shape memory alloy (Fe-SMA), also known as memory steel, has been shown in several scientific investigations. These techniques have high potential for being cost effective ways to strengthen and prestress existing concrete structures. For more than two years, these new strengthening methods have also been available on the construction market. Several site applications have been carried out so far, including externally applied memory-steel strips and near-surface mounted ribbed memory-steel bars. This study describes selected site applications.
The first site applications present the installation and activation of end-anchored memory-steel strips (re-plate). The strips were mechanically fixed to the concrete substrate using a direct-fastening system with nails. Activation of the shape-memory effect and hence prestressing was accomplished either by resistive or infrared heating. On one object, successful reduction of existing crack width was demonstrated and monitored with Omega-deformation gauges. The temperature of the strips was monitored with thermocouples or a built-in sensor.
In a second application category, memory-steel bars (re-bar) were used to strengthen a cantilever slab of a residential building in the negative bending moment area. After grooves were cut into the concrete surface, the bars were inserted and bonded at both ends with a cementitious mortar. The shape-memory effect was activated by infrared heating of the bar over its unbonded length. After the bar-temperature had reached ambient level again, the remaining groove was also filled with mortar. In this site-application, heating of the memory-steel was monitored with temperature sensors.
Building owners, contractors, as well as structural engineers responded very positively to the novel strengthening techniques. The presented examples demonstrate the successful application of new effective strengthening methods for retrofitting of existing concrete structures using memory-steel products.

Tu.3.A.4 16:15

'memory steel' for Shear Reinforcement of Concrete Structures

M. Shahverdi [1], C. Czaderski [1], J. Michels [1,2]
[1] Empa, Dübendorf, Switzerland; [2] re-fer AG, Brunnen, Switzerland

Strengthening of reinforced concrete (RC) structures is generally used to increase either their bending or shear resistance. The latter is usually performed with fiber reinforced polymer (CFRP) by means of the near-surface mounted (NSM) strengthening technique (bars), or by external bonded CFRP fabrics and strips. In case of a prestressed shear strengthening, several advantages can be obtained due to the prestressing force: closing of existing cracks, reducing the force in the internal stirrups, delaying the appearance of new cracks, and increasing the ultimate shear resistance. However, technical implementation is complex.
Empa and re-fer AG developed strengthening products from a new iron based shape memory alloy (Fe-SMA), also denominated as memory-steel. A shape memory alloy (SMA) has the unique property to remember its initially given shape upon heating after having been deformed over elastic extent. This memory steel can be used as a prestressing system for concrete structures.
In the current study, small scale experiments for investigating the overall principle have been carried out. These experiments demonstrated the feasibility of such a Fe-SMA shear reinforcement. Additionally, T-beams with a span of 5 m have been experimentally examined to study the application of memory steel bars for pre-stressed shear strengthening. The ribbed memory steel stirrups have been used in combination with shotcrete mortar. An important finding was the fact that the bending of the stirrups in the corners did not hinder the system to work. The application finally enhanced the structural behavior of the RC members as the shear cracks width can be reduced and new shear cracks occur under higher loads.

Tu.3.A.5 16:30

Damping devices using single & dual SMA rings

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This study introduces the use of SMA rings as self-centering and damping devices. Cyclic tests on single and dual rings systems have been conducted. Both austenitic or superelasticity (SE) and martensitic (MA) SMA have been used to manufacture SMA rings. Based on the use of SMA and number of rings, five specimens have been named as follow: single superelasticity ring (SE), single martensitic SMA ring (MA), two superelastic SMA rings (SE-SE), two martensitic SMA rings (MA-MA), and martensitic-superelastic SMA rings (MA-SE). Experimental results show that while the single SMA ring systems in this study showed better symmetrical behaviors in comparing to a previous study, the dual rings systems show perfect symmetrical behaviors. The damping capacity has been investigated through a damping ratio. Experimental results show that it is recommended to use MA in SMA rings system if the damping capacity is a priority. On the basis of a displacement recovery ratio (DRR), the self-centering capacity of SMA ring systems has been investigated. It is believed that the use of SE in SMA rings systems could provide higher self-centering capacity in comparing to MA SMA. In addition to experimental studies, a numerical model of the supperelastictiy SMA ring systems is also developed using Ansys software. Furthermore, to examine the effect of the thickness of SMA rings to the symmetrical behavior of the single SMA systems, a thickness ratio and a pseudoelasticity stiffness ratio has been introduced. The analysis results obtained from Ansys demonstrate that an increase in the thickness ratio leads to a decrease in the stiffness ratio. Therefore, the ring could behave symmetrically when the thickness of the ring reaches a critical value. However, due to the p-delta effect when large displacement have been applied, the unsymmetrical behavior still occurs. Thus, in order to provide a symmetrical behavior, it is supposed to use dual SMA rings systems or 2 rings at symmetrical structures.

Tu.3.A.6 16:45

Potentials and challenges for Fe-Mn-Al-Ni-X iron based shape memory alloys in civil engineering

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Iron-based shape memory alloys, i.e. Fe Ni Co Al X (Ta, Ti, Nb) and Fe Mn Al Ni-X (X = Ti, Cr), are promising candidates for functional mass applications, e. g. damping elements for bridges and skyscrapers. Some of the biggest advantages of Fe-based alloy systems are the comparatively simple processing routes originating from steel industry and the relatively low material costs. However, microstructural issues related to phase fractions, grain sizes, grain morphologies and grain orientations as well as functional fatigue have to be overcome for any industrial application.
The current study highlights recent progress in processing, microstructure properties as well as mechanical properties of the Fe-Mn-Al-Ni-X shape memory alloy system. Especially the control of the grain size through abnormal grain growth introduced by a cyclic heat treatment, grain boundary engineering by controlling the cooling rate from quenching and functional fatigue properties of the alloy system will be in focus of the paper.
Properties were characterized by means of in situ mechanical testing, scanning electron microscopy, electron backscatter diffraction, transmission electron microscopy, energy dispersive X-ray spectroscopy, optical microscopy and dilatometry. From the results obtained so far the high potential as well as the challenges for Fe-Mn-Al-Ni-X to be used as a shape memory alloy for applications in civil engineering will be discussed.

Tu.3.B | DAMAGE CONTROL, REPAIR AND STRENGTHENING (II)

Tu.3.B.1 15:30

Bond resistance of prestressed CFRP strips to concrete substrate: comparative evaluation of EBR and EBROG methods

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Application of Fiber Reinforced Polymer (FRP) for rehabilitating existing concrete structures is well-known nowadays. Externally Bonded Reinforcement (EBR) method is usually used to apply FRP composites on the concrete surface. However, a premature debonding failure mode may occur prior to achieving the full capacity of the strengthened section. The newly developed Externally Bonded Reinforcement On Groove (EBROG) method was shown to extensively postpone the debonding failure mode.
In this paper, bond behavior of prestressed FRP to concrete was investigated. Concrete blocks were strengthened with EBR and EBROG methods using prestressed Carbon FRP (CFRP) strips. The prestressing force was gradually decreased until the CFRP strip was debonded from the concrete substrate. Through this prestress force-releasing test, the bond resistance of prestressed FRP to concrete was measured. Experimental results showed that EBROG method increased the bond resistance twice the EBR method. This high increase is attributed to the failure mode of the specimens. While the debonded layer in EBR method was a few millimeters beneath the FRP strip, it was deep and wide in the concrete substrate for EBROG method.

Tu.3.B.2 15:45

EBROG technique to enhance the bond performance of CFRP strips to concrete substrate

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A well accepted retrofit technique in the civil industry is the application of carbon fiber reinforced polymer (CFRP) reinforcement by using structural epoxy adhesives to strengthen existing reinforced concrete members. Usually, the concrete surface has to be ground or sand blasted, prior to the application of CFRP strips. Although the technique is quite fast and easy, its major problem is the premature debonding failure of the CFRP reinforcement, when the strengthened member is subjected to external loading up to failure. This undesired failure mode occurs because the tensile strength of the concrete is limited.
In this paper, bond performance of a recently introduced technique, called externally bonded reinforcement on grooves (EBROG) is investigated. The technique uses longitudinal grooves cut into the concrete surface in order to better distribute the interfacial shear stresses to deeper layers of concrete substrate, and consequently, to increase the CFRP-to-concrete bond resistance. Sets of lap-shear and four-point beam tests strengthened with the conventional externally bonded reinforcement (EBR) in comparison to EBROG technique are described. Experimental results demonstrated the great potential of EBROG technique for the strengthening of existing concrete structures.

Tu.3.B.3 16:00

Test study for full-scale hollow slab girder using UHPFRC reinforcement technology

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High performance fiber reinforced concrete (UHPFRC) is an optimal choice for concrete bridge reinforcement, which can significantly enhance structural resistance and durability of structural members. Rational reinforcement methods based on UHPFRC are explored for improving both bridge performance and structural utilization efficiency, to achieve life cycle cost economy. In this paper, full scale hollow slab girders were selected for loading behavior study before and after reinforcement, which were derived from an in-situ bridge. Test study was conducted for one full scale hollow slab girder in order to study their residual load carrying capability. Based on damage inspection result and residual performance study for hollow slab girders, reinforcement measures were determined for another full-scale test girder, including steel plate and UHPFRC composite reinforcement for bottom plate, and composite UHPFRC layer for top plate. After test study, the behaviors of hollow slab girders were comparatively analyzed, including capacity, fductility, overall behavior and rigidity.

Tu.3.B.4 16:15

Strengthening Glued Laminated Non-circular Timber Columns With CFRP Jacketing

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Recent developments in polymer and composite industry brought new solutions in construction techniques. In this study, compression tests are executed on glued laminated timber (glulam) columns confined with carbon fibre reinforced polymer (CFRP) sheets to assess potential enhancement in the structural performance of these members due to external confinement. In the experimental program, 8 timber column specimens were tested after jacketing with 1 and 3 plies of CFRP sheets and two columns were tested as reference specimens. Before external confinement with CFRP sheets, the corners of six of the columns were either rounded to 30 or 40 mm. Two columns were externally confined without rounding their corners. The aim of this investigation is to evaluate the failure modes and the stress-strain relationships of the externally confined specimens and to study the effect of the corner radius on the behaviour. At the end of the test, it was seen that external reinforcement using CFRP jackets have resulted in a significant increase in deformability. The improvement was more pronounced for the specimens jacketed with 3 plies of CFRP sheets with the corner radius of 30 mm.

Tu.3.B.5 16:30

Experimental program on large-scale reinforced concrete columns strengthened with carbon FRP jackets

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One of the most attractive applications of FRP composite materials is the confinement of concrete columns to increase both strength and ductility. Numerous experimental studies have been carried out, most of them on small scale cylindrical specimens. Further experimental research needs to be conducted on large-scale columns, very limited to date. Several empirical models have been proposed that have been adopted by the design guides published in various countries.

It is well known that the confinement of square or rectangular columns is less efficient than the confinement of circular columns. In the theoretical analysis of rectangular sections, models found in current design guides are usually based on models created for circular columns and then modified by a shape factor. This paper presents the results of tests carried out on full scale CFRP confined columns subjected to axial compression load. Four columns have been tested: three specimens strengthened with carbon FRP and one control specimen (unstrengthened). The columns have a height of 2400 mm and cross section of different aspect ratios. The tests results show that the FRP confinement can increase the strength and ductility of concrete columns of rectangular section with rounded corners. The stress-strain behaviour and strength gain depends on the aspect ratio. The hoop rupture strain of the FRP jacket is much lower than the material ultimate tensile strain obtained from flat coupon tests. The proposals of different design recommendations are reviewed and compared with the experimental results of this work (ACI-440.2R-17, Concrete Society TR55 2012, CNR-DT 200 R1/2013).

This work is part of the Project BIA2016-80310-P, funded by AECI and FEDER. The authors acknowledge Betazul S.A. and SIKA S.A.U. for performing the strengthening work and providing testing materials. V. J. Castro acknowledge Spanish MICINN and European Social Fund the financial support (FPI grant BES-2017-080647).

Tu.3.B.6 16:45

Influence of multiple anchors´ arrangement in the behaviour of FRP-to-concrete anchored joints

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The effectiveness of FRP externally bonded reinforcements is limited by its premature delamination from the substrate. In recent years, various anchoring systems have been developed for FRP sheets. Among these systems, FRP anchors also known as spike anchors stand out since they are manufactured with the same fibre as the reinforcement, guaranteeing their compatibility with both substrate and reinforcement. The effectiveness of FRP anchors has been demonstrated in numerous experimental campaigns, managing to delay debonding or even change the failure mode. The design of the FRP anchors has to be adjusted to the needs of the reinforced element; multiple anchors will be required when the unit resistance of a connector is insufficient. The influence of multiple anchors in terms of strength and ductility of anchored reinforcements is determined mainly by the type of distribution and alignment, transverse spacing and longitudinal spacing. The width of the sheet must be taken into account to decide between the possible arrangements since it´s accepted that the anchor´s fan must fully cover the cross section of the sheet to enhance the joint strength. For strips and narrow sheets the longitudinal distribution can be effective; the ultimate load of the reinforcement will in this case be determined by the capacity to delay debonding of the anchors located closer to the loaded end, while additional anchors may enhance ductility of the joint. In this campaign single shear tests were performed on CFRP anchored sheets in concrete substrates. The 100 width sheets were considered narrow and thus only one anchor was installed in all in all 100 width FRP sheets and in the first series of 200 mm width sheets. Two anchors distributed transversally covering the entire width of the sheet were studied in the last series of this campaign for the 200 mm FRP width sheets with the aim of evaluating the influence of multiple anchors.

Tu.3.C | SHM – SMART SENSORS (I)

Tu.3.C.1 15:30

Integrated Optics Inclinometers for SHM

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Inclinometers are used in a variety of monitoring applications in civil and geotechnical engineering. Together with strain, displacement and pressure, tilt is one of the most important indicators of structural health and performance. Inclinometers are also used to monitor subsurface movements and deformations.

Typical applications include:
- Detecting zones of movement and establish whether movement is constant, accelerating, or responding to remedial measures,
- Verifying stability of dams, dam abutments, and upstream slopes during and after impoundment,
- Monitoring settlement profiles of embankments, foundations, and other structures (horizontal inclinometer),
- Detect differential settlements in buildings and bridges that produce a tilt of the structure,
- Monitoring of oil&gas structures such as off-shore platforms, risers.

Currently, the most used tilt sensors are based on electrical sensors. These electrical technologies have limitations in their use when electromagnetic disturbances are present, e.g. in proximity of train lines or in structures subject to lightning strikes. The maximum cable length is also limited for electrical sensors, which poses a problem for the monitoring of very large structures, in particular dams and dykes. Optical fiber sensors are typically used to address those limitations thanks to their insensitivity to EM interference and the ability to transmit information over long distances. Some Optical Fiber Inclinometers have been developed in the past but are typically bulkier and more expensive than the conventional sensors and offer inferior performance. Existing fiber optic tilt sensors are based on conventional mechanical concepts with mechanical pendulums applying strain to a sensing optical fiber. Because of the fiber rigidity, large masses are required in the pendulum and this makes the sensors bulky and expensive.
In this contribution we present the development, qualification and testing of a novel fiber optic inclinometer based on integrated optics microfabrication. The new device offers performances in line with the standard electrical tilt sensors, is small and light and is compatible with existing Fabry-Perot readout modules already used to measure other optical fiber sensors (e. g. strain, temperature, displacement and water pressure sensors).

Tu.3.C.2 15:45

Surface-applied distributed fiber-optic monitoring for crack detection in concrete structures: Technology overview and application challenges

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Truly distributed fiber-optic strain measurements provide the possibility to detect and quantify cracks in prestressed concrete structures without previous knowledge of the location where cracks are likely to appear. In the specific case of existing structures, where embedding sensors into the concrete is not possible, surface application of fiber-optic sensing cables is a feasible way for retrofitted structural health monitoring.
With the Distributed Brillouin Optical Frequency Domain Analysis (BOFDA) and the coherent Optical Frequency Domain Reflectometry (c-OFDR), two complementary technologies have been applied to crack measurements on prestressed concrete beams within the scope of this work. The c-OFDR technology provides millimeter-range spatial resolution over some tens of meters of range, whereas the BOFDA technology offers a spatial resolution down to 20 cm, but enables measurement lengths of several tens of kilometers.
This article highlights the strengths and challenges of both technologies, with special focus on the differences in how the fiber-optic sensors are applied to achieve optimum results. Comparisons of different fiber and cable types are made as well as different bonding techniques like continuous and point-wise gluing and anchoring.
The nature of distributed strain data also differs between the technologies: While c-OFDR delivers strain data derived from the geometrical information of the fibers elongation by means of analyzing the Rayleigh backscatter distribution along the fiber, BOFDA uses the fibers local density to derive an absolute quantitative strain value. The implications for analyzing the data from both technologies are shown and verified by experimental data from true-scale laboratory tests and on-site applications.

Tu.3.C.3 16:00

Fibre-optic sensors in practical applications: challenges and technical needs for a successful use

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Fibre-optic sensors are widely used because of their technical and economic benefits. The scientific background is usually well developed; however, there are sometimes restrictions with respect to long-term reliable behaviour of sensor components and/or the long-term stability of the application itself. The first challenge when a decision for any sensor system has to be made is the appropriate selection of the sensor system that provides the required monitoring characteristic. In order to minimize problems in practical application of new sensor technologies, basic rules of validation and of on-site evaluation as well as guidelines and standards should be considered. Very important is, on the other hand, a well-understood communication between the owner and/or user of the structure and manufacturers of sensor components, physicists, and experts which apply sensors. All experts involved in different stages of the development process to create an efficient sensor system, should follow guidelines on how to specify the characteristics of the sensor system and characterize the sensor systems behaviour under all expected environmental loads and attacks. One of the most critical aspect concerns the evaluation of the sensor systems long-term operation on-site.
The presentation will focus on different essential aspects to achieve a long-term stable and reliable sensor system – the basis for a trustworthy monitoring system. Corresponding selected examples will be shown. The presentation will also provide news in related international standardization activities.

Tu.3.C.4 16:15

Self-Sensing Carbon Nanotube Reinforced Composites for Smart Cities

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Self-sensing composite materials are becoming attractive for civil engineering application to improve the safety and performance of structures. Current structural health monitoring still requires many sensing devices and technicians for their visual inspection, which are expensive and time consuming. Proposed self-sensing composite materials consisting of carbon nanotubes and polymer provide innovative way for structural health monitoring. The smart composites show significant change in their electrical resistance with applied

loadings such as static and impact loadings. In this study, we will fabricate highly conductive carbon nanotube reinforced composite materials for sensor integrated construction materials. The author reports materials design and optimisation of carbon nanotube reinforced composite materials in terms of electrical conductivity and mechanical property. Moreover, we investigate the electro-mechanical response of carbon nanotube reinforced composite materials under static and impact loadings. Finally, we will present new Internet of Things (IoT)-based sensing system that capture various data from smart composite material itself without any additional sensing elements.

Tu.3.C.5 16:30

A hybrid optical fiber/wireless monitoring system for permeable pavements

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This paper presents the development and assessment of a novel hybrid optical fiber/wireless monitoring system for permeable pavements. The real-time hybrid fiber optic/wireless permeable pavement monitoring system can be used to simultaneously measure flow discharge, temperature, flow velocity, and water level using the advantages of Mach-Zehnder interferometer (MZI) and Arduino-based sensing technologies. There were two types of water-flow velocity simultaneous measurements: inflow and drainage processes. For the inflow and drainage processes, the differences between the MZI-based water-flow velocities and the Arduino-based wireless water-flow velocities were found in the range of 3.64.4%. We have demonstrated the feasibility of the novel hybrid optical fiber/wireless monitoring system for permeable pavements simultaneously for water level, flow discharge, temperature, and flow velocity measurements without modifying MZIs or coating chemical compounds. Hopefully, the findings of this study can be utilized to establish the real-time multiplexing hybrid optical fiber and Arduino-based monitoring system for different types of permeable pavements.

Tu.3.C.6 16:45

A Coupled Damage-Plasticity Traction-Separation Law for Masonry

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Due to the inherent brittleness, catastrophic collapse and damage of masonry structures can occur abruptly when the load-carrying capacity is exceeded. Failure of masonry structures in earthquakes and other extreme loading has been a major concern for the structural designers. Robust design of the structure relies on the accuracy of the structural response analysis under different loading conditions. Macroscopic strut-and-tie models and simplified continuum models are often used but they may not be able to simulate the detailed structural damage and the progressive collapse of the masonry structures. To this regards, a new and robust interfacial constitutive law, which couples the damage and plastic deformation with fracture energy-based softening rules, has been developed for the discrete finite element modelling (DFEM) of masonry structures. The model has 14 required parameters and the proposed model can successfully simulate a variety of mechanical behaviour of masonry structures including the pressure-dependent strength and fracture, wearing-off of the friction, dilatation behaviour, stiffness degradation, shear retention, and disintegration of the components. Several experiments on the masonry were simulated and good agreements between the simulated and experimental results could be observed. Comparing to the conventional microscopic models, the DFEM with the coupled damage-plasticity interfacial constitutive law can significantly simply the meshing work and the control of the mesh quality. Hence, the proposed model can be a practical tool for reliable failure and collapse analysis of masonry structures.

Tu.3.D | PERFORMANCE AND DAMAGE ASSESSMENT – SAFETY EVALUATION AND RELIABILITY FORECAST

Tu.3.D.1 15:30

Structural evaluation of a reactor building during pressure leak-rate testing for life extension assessment

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As a part of a life extension project, a full scale pressure test has been carried out at the Embalse NPP, located in Córdoba (Argentina). The testing consisted of applying a differential pressure of 124 kPa inside the reactor building in order to represent the design basis accident. Both leakage rate and structural deformations were monitored at several locations inside the building, in order to evaluate the response of the prestressed concrete containment structure with respect to model predictions considering linear elastic response. Given the fact that the testing was performed over several days, where significant thermal fluctuations took place, both internal and external temperatures were recorded before, during, and after the testing. The thermal records were then represented in a numerical model, as resulting deformations were on the same order as the ones due to the differential pressure. This paper describes the pressure test, instrumentation, and results, with particular emphasis on the modeling procedure to account for the rather complex thermal variations that took place during the test, and that had to be filtered out in order to assess the response of the building due to the applied pressure.

Tu.3.D.2 15:45

A Proposed Approach for Processing and Analyzing Strain Data Collected In Full-Scale Accelerated Pavement Testing

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This study presents a general methodology for analyzing strain measurements collected during Accelerated Pavement Testing (APT). Data from three full-scale pavement sections at Rowan University was collected from embedded asphalt strain gauges. The sections had similar supporting layers (a 12 in. (304.8 mm) compacted natural subgrade, a 16 in. (406.4 mm) granular subbase, and an 8 in. (203.2 mm) Portland cement concrete (PCC) base layer). Three

different asphalt overlays were placed on top of these (Section 1 was overlaid with a 3 in. (76.2 mm) SMA layer, Section 2 was overlaid with a 2 in. (50.8 mm) NJHPTO layer, and Section 3 was overlaid with a 2 in. (50.8 mm) 9.5 ME Superpave mix placed on top of a 1 in. (25.4 mm) BRIC layer). The sections were loaded using a heavy vehicle simulator (HVS) test wheel having dual-tire single axle configurations. A 60 kN load was applied on the section in a unidirectional manner at a speed of 8 mph (5 km/h) for a total of 200,000 loading passes. Using the recorded strain data obtained from all three sections, two parameters (i.e., asphalt layer Modulus (EAPT) and cumulative damage index (DI)) were computed and their ability to distinguish the fatigue performance of the asphalt overlays was evaluated. The general APT strain data analysis approach was successful at distinguishing the fatigue performance of asphalt overlays. The analysis also showed that the cumulative DI parameter was more capable than the EAPT parameter at ranking the realistic fatigue performance of the sections.

Tu.3.D.3 16:00

A practical approach for modeling tendon and wire failures for model-based damage detection of prestressed concrete bridges

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Predictive maintenance management, which eliminates structural deficits before secondary damage occurs, offers great potential to meet the challenges of an ageing infrastructure. The OSIMAB project follows this strategy and merges expertise from different disciplines into a holistic approach for monitoring and assessment of road bridges.
The starting point lies in the analysis of the building stock based on existing data sets such as climate, traffic and building data. They are supplemented by additional information from the permanent structural monitoring of relevant individual structures. The usage of innovative data mining algorithms as well as calibrated finite element models provide a redundant tool for early detection of structural changes and deficits. The concept is completed with a risk analysis which considers a safety concept adapted to the current structural condition. This paper focuses on the results of the model-based damage detection, a method based on a comparison of simulated and measured sensor data. Road bridges are exposed to a variety of actions, of which penetrating de-icing salts and dynamic traffic loads often lead to the most serious damages. In the worst case, fractures of the tendons emerge, whose limited visual recognition makes them particularly suitable for monitoring-based damage detection. A method for modeling tendon and wire fractures will be presented that efficiently takes into account important effects such as the re-anchoring of the tendons in the grout. The correctness of the procedure can be guaranteed by recalculating experiments, the practical relevance by applying the method to a T-beam of a real bridge. A numerical simulation of a damaged bridge girder is used to demonstrate possibilities of detecting and localizing damage with a finite element update.

Tu.3.D.4 16:15

Possibilities to Enhance Tomography Imaging of Concrete Structures by the Full Waveform Inversion

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It is a state of the art to test concrete specimen with ultrasonic-based methods. However, due to the density and the required high resolution, the testing is done with high-frequency waves which cannot penetrate the structure in depth.
Adopting techniques used, e.g., in geotechnical applications, a model-based inversion using higher wavelengths is proposed, which is the full waveform inversion. This approach is however non-linear, time-consuming and highly ill-posed.
Thus, further developments are necessary to make the technique applicable to structures like dams, dikes or similar. Among these developments are further accelerations of the so-called forward codes by a more efficient implementation of the wave equation. To handle with the ill-posedness, regularization techniques need to be applied and tested in order to reduce the risk of incorporating too many and misleading artifacts in the resulting images. This, e.g., can be done by the consideration of a priori knowledge of the material properties inside a structure which could be taken from already well-established inspection methods.
Some first results, mainly based on synthetic data, will be presented to show the capabilities of the model-based approach.

Tu.3.D.5 16:30

Application of Gaussian process metamodel in structural finite element model updating applying dynamic measured data

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Civil infrastructure is vital linking component whose behavior is necessary to be monitored continuously since any fault in performance will cause significant risks. Recently, structural health monitoring (SHM) has obtained a significant contribution in preparing information related to structural behavior during functional life. Though, determining real infrastructure‘s behavior is intricate, since it relies on structural parameters that cannot be obtained directly from observed data and such identification is prone to uncertainties. Finite element model updating (FEMU) is an approach to address this issue. The current study employs a Modular Bayesian approach (MBA) to update a finite element model (FEM) of a lab-scaled box girder bridge applying natural frequencies. This approach is performed in two stages as undamaged and damaged. These stages can be denoted as the change in structural parameters due to incidences such as impact or fatigue effect. The performed MBA deals with uncertainties thoroughly in all steps. In this study, a discrepancy function is applied to detect the discrepancy in natural frequencies between the FEM and the experimental counterpart. A Gaussian process (GP) is used as a metamodel for the simulated model and the model discrepancy function. In this research, updating the initial FEM of the lab-scale Box Girder Bridge (BGB) by calibrating multi parameters is highlighted. Results specify a considerable drop in stiffness of concrete in damaged phase which is well matched with the cracks

observed on the structure's body. Also, discrepancy records reach satisfying range in both stages which implies the structure's properties are predicted accurately.

We.1.A | KEYNOTE PRESENTATIONS

We.1.A.1 08:30

Mismatches between design and condition assessment in reinforced concrete with or without FRP strengthening

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Initial design does not explicitly provide a framework to understand the time-dependent evolution of structural resistance. In-service load and environmental histories are unknowable. So how can we best assess the condition of an existing reinforced concrete structure at a particular time; and address potential structural vulnerabilities going forward? A piece of this puzzle is to establish a better connection between deterioration outcomes and structural performance to inform existing strength assessment. Methodologies developed in the context of reinforced concrete half-joint structures are presented as examples. When then seeking to increase or reinstate strength, a further puzzle piece is a critical analysis of the role of strengthening interventions. Strength enhancement arises from different sources and FRP shear strengthening research is used to demonstrate various contributions. It is argued that lumping these sources together, as is commonly done in current FRP strengthening design practice, distorts our fundamental understanding of how strengthened reinforced concrete structures behave over time. This creates a further future mismatch between design and condition assessment but now for a structure with FRP strengthening. We thereby risk extending our current quandaries to structures post-intervention.

We.1.A.2 09:10

Damage control, repair and strengthening of concrete arch bridges in China

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Concrete arch bridge is one of the main type of bridges in China. Many of them are in service in the road systems today. The history is briefly reviewed. The establishment of technical archives, field inspection, condition rating is introduced. Their damage control, repair and strengthening as other type bridges are introduced, focusing on their special characteristics. There are many light concrete arch bridges in the Chinese road systems, which were very economic and favored structures in the period between 1960s-1980s when construction materials and equipment have been rare. Now they have severe defects, such as deficient stiffness, low load bearing capacity or poor connections. The main problems of light weight concrete arch bridges and how to repair and strengthening them are presented with some case study. The bridges include double-curved arch bridge, disc arch bridges (truss arch bridge, rigid-frame arch bridge) and prestressed truss arch bridges. Another big problem of Chinese concrete arch bridges is the deck failure caused by broken suspension cables. Some accidents are presented, and the causes of their collapse are analyzed. Finally, appropriate strengthening measures are proposed to prevent failure.

We.2.A | SHAPE MEMORY ALLOYS (SMAS) FOR ENGINEERING APPLICATIONS (III)

We.2.A.1 10:30

A simplified model for the shear strength in RC and PC beams, and for punching shear in slabs, without or with shear reinforcement, including steel, FRP and SMA

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Shear in beams and punching shear in slabs, is a long-time hot topic for design and safety evaluation. Due to the brittle behavior in shear of the reinforced concrete (RC) and prestressed concrete (PC) members, the assessment of existing structures must be carried out using reliable models, and, if possible, models based in the mechanical principia, in order to clarify the physics behind the failure for practicing engineers.
In this communication, a simplified model for shear in beams and punching shear in slabs will be summarized. The same mechanical model, originally derived for concrete beams reinforced with fiber reinforced polymers (FRP) longitudinal and/or transversal reinforcement, has been extended to many different particular cases, following always the basic mechanical principia usually considered in structural engineering. The model can be currently applied for two way slabs, one-way slabs and reinforced concrete or prestressed beams. For beams, the case of slender and non-slender beams may be solved in a continuous way, including the possibility of considering the different behavior of beams with rectangular, T- or I-cross section, or different shear reinforcement materials, such as steel, FRP or shape memory alloys (SMA).
The shear strength predicted by the proposed simplified equations has been compared with the experimental results of 2399 tests and with the predictions by the Eurocode 2 and a more general background model also derived by the authors.

We.2.A.2 10:45

The development of memory steel at Empa

C. Czaderski [1], *M. Shahverdi* [1], *E. Ghafoori* [1], *M. Motavalli* [1], *C. Leinenbach* [2], *A. Arabi-Hashemi* [2], *J. Michels* [3], *J. Scherer* [3]
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Shape memory alloys have the unique property that they remember their shape after they have been deformed, either immediately upon unloading or by heating above a critical temperature. This shape memory effect can be used to prestress concrete without the need of ducts, anchor heads, and oil hydraulic cylinders. However, most of the commercially available shape memory alloys are made of Nickel Titanium (NiTi), and are too expensive for a broad application in the construction industry. Therefore, an iron-based shape memory alloy

(memory steel) with lower production costs, which is more suitable for concrete reinforcement was developed at Empa. The company re-fer AG was founded in 2012 with the goal to establish memory steel reinforcements on the market. In this paper, investigations and developments by a multidisciplinary team at Empa during more than 15 years in the field of concrete prestressing with memory steel are outlined. The impressive and long way from first trials with NiTi wires up to the industrial production of memory steel strips and bars and site applications to renovate buildings with memory-steel is described.

We.2.A.3 11:00

Improvement of FeMnSi based shape memory alloys yield stress by heat treatment

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Iron-based shape memory alloys (Fe-SMAs) attract more and more attention in recent years. The improvement of the shape memory effect (SME), i.e. recovery strain, has been extensively studied. In civil engineering, Fe-SMAs can be used as pre-stressing elements for concrete structures. For this application, recovery stress of Fe-SMAs is an essential characteristic to evaluate the reinforcement ability and large value is preferred. However, it is acknowledged that high recovery strain does not always correspond to high recovery stress. Investigation to improve recovery stress of Fe-SMAs is pressing in real application. High yield stress and SME are beneficial to achieve high recovery stress, and these two factors are strongly dependent on the aging conditions for the FeMnSi with precipitates type shape memory alloy. This paper investigates the influence of different aging conditions on the yield stress and pseudoelasticity εpe of the Fe-SMA. It is shown that the maximum 0.1% yield stress reaches up to 672MPa upon aging at 600°C with 72h holding time.

We.2.A.4 11:15

Axial stiffness of a Fe-SMA during the activation process

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A shape memory alloy (SMA) is a material which can return into a predefined shape upon heating or unloading after being subjected to deformation. If this reverse process is prevented by a mechanical fixation, stress is developed in SMA element. The generated stress, typically identified as recovery stress, enables a SMA material to be used as a pre-stressing element for reinforced concrete structures in civil engineering. The process of heating a SMA to a target temperature and cooling it down to room temperature while keeping the strain constant is called activation. The activation simulates what occurs in a SMA used as a pre-stressing element in concrete structures. A novel iron-based shape memory alloy (Fe-SMA) with the composition of Fe-17Mn-5Si-10Cr-4Ni-1(V, C) (mass %) was designed at Empa. This new Fe-SMA offers promising thermo-mechanical properties since the recovery stress can achieve more than 300 MPa without any additional training process. During the activation process, the developed force between a Fe-SMA element and concrete depends on the axial stiffness of the Fe-SMA strip (k_SMA) and the substrate element. The current study investigates the evolution of a variable modulus E_SMA (k) during the activation process. The obtained results can be used in analytical and numerical modeling involving the calculation of interaction forces between SMA elements and the substrate structure.

We.2.A.5 11:30

Bond behaviour of near-surface mounted iron-based shape memory alloy bars

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The use of iron-based shape memory alloy (Fe-SMA), so-called memory steel elements for strengthening of existing concrete structures has high potential for being a competitive option to established methods. The prestressing function is obtained by activating the shape memory effect - that is, the ability of the material to return to its original shape after deformation, when heated. If the SMA element is restrained on a structure when heated, stresses will developed in the element and consequently also in the structure. The underlying idea of the current investigation is to mount ribbed Fe-SMA bars into grooves in the cover of concrete elements with a cementitious mortar, which is called near-surface mounted (NSM) strengthening technique. In the current study, the bond behaviour of NSM Fe-SMA bars was investigated by means of pull-out tests. The aim was to study the influence of the groove dimensions and to find an optimal configuration, which could be used in a real application. The obtained average bond stress - slip behaviour can furthermore be implemented in analytical and numerical calculations.
Specimens consisted of concrete cubes, where grooves were cut into one surface and Fe-SMA bars were embedded to, on a bond-length of five times the bar diameter. The Fe-SMA bars were then subjected to tensile loading, i.e. pull out load. The design of the experiments was based on RILEM specifications. Besides pull-out load and end-slip, full-field deformations were measured with a 3D digital image-correlation system (DIC). The tests delivered satisfying results in terms of load capacity and slip.
Two main failure modes were identified, which were either based on shearing of the mortar substrate adjacent to the ribs, or splitting of the cover and surrounding concrete. It was also found that the groove depth and therefore the cover thickness highly affect the bond capacity and mode of failure. The groove width did not influence either the load capacity or the slip significantly. In general, near-surface mounted Fe-SMA bars show sufficient bond performance for the use as a structural strengthening method.

We.2.A.6 11:45

Shape memory alloy fibres in fibre-reinforced ultra-high performance concrete – Rheology optimization and bonding behaviour

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In this work, the use of Shape Memory Alloy (SMA-) fibres is proposed to introduce a novel class of functional fibre reinforcement. Fibre

reinforcement of Ultra-High Performance Concrete (UHPC) is used to increase its tensile and flexural strengths as well as to establish a more ductile post-failure behaviour compared to the brittle post-failure behaviour of non-reinforced UHPC. In contrast to the improvement of the mechanical behaviour of hardened concrete, the workability of fresh concrete decreases due to the fibre reinforcement, especially for fibre contents > 2 vol.-%. Hence, in one approach the fibres are used to combine the positive characteristics of hardened fibre reinforced concrete with a good rheology and, therefore, workability of the fresh concrete. SMA have the ability to transform into an imprinted geometry upon heating. SMA-fibres with a shape that is favorable for the rheology of the fresh concrete are added to the concrete. While the concrete is still flowable, the fibres are activated due to external heating and transform into their imprinted geometry that promotes the mechanical properties of the hardened concrete. Investigations have shown, that a circular shape of the fibres enhance the viscosity of the fresh material significantly. Furthermore, SMA made of nickel and titanium (NiTi) are able to transform into in their imprinted geometry in fresh UHPC. In another approach the fibres are used to prestress UHPC components internally to enhance the tensile and flexural strengths of the material. Pre-stretched, straight SMA-fibres are added to the fresh concrete. After hardening of the concrete, the fibres will be activated upon external heating. As they intend to contract, the fibres transfer a compressive prestress into the concrete due to the bonding between fibre and matrix. This compressive stress will counteract the tensile stress that the component will receive in its later function. However, in first investigations a prestress could not be achieved due to a low bonding strength between NiTi-fibre and cementitious matrix. For both methods the bonding between fibre and cementitious matrix is an essential factor as it is mainly responsible for the tensile and flexural strengths of the hardened UHPC. Investigations have shown that NiTi, the widely known and most available SMA, has a worse bonding behaviour compared to traditionally used steel fibres. In contrast, Fe-based fibres have a much better bonding between fibre and concrete.

We.2.A.7 12:00

SMA-Reinforced Concrete Shear Walls Subjected to Reverse Cyclic Loading

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In response to the challenges that arise in developing resilient structures to seismic events, novel structural systems integrating emerging materials are developed as alternatives to current conventional structural solutions. Over the last decade, one such material that has gained popularity among researchers is Shape Memory Alloys (SMAs). This material can provide two distinctive responses that are contingent on the intended application. SMAs are used either in the Shape Memory form, where an external heat source is required to initiate a recovery of residual strains in the material, or as a Superelastic (SE) material, where the recovery of strains initiates during the unloading phase. Shape Memory SMAs have found applications as active prestressing for structural components, whereas Superelastic SMAs have been implemented as the principal longitudinal reinforcement in critical zones of structural components as replacement of the traditional black carbon steel. In such applications, the SMA-reinforced concrete component is expected to exhibit a self-centering characteristic. More recently, SE-SMAs have been exploited as a retrofitting material to improve the response of seismically deficient structures. The focus of this paper is to present experimental results of a slender concrete shear wall reinforced with SE-SMA reinforcement. Shear walls are routinely selected as the seismic force resisting system in concrete construction in Canada. Furthermore, shear walls, specifically perimeter walls, support a low level of axial load and, thus, significant inelastic response to seismic loading is expected. This leads to large plastic deformations and the potential for significant residual drift. For this reason, shear walls are good candidates for the inclusion of SE-SMAs as principal reinforcement in critical areas. Testing of the SE-SMA reinforced wall illustrated the capacity of the wall to recover inelastic displacements to a larger extent in comparison to a companion steel-reinforced wall. In addition, the SMA wall experienced more localized cracking, specifically at the base of the wall, which controlled the response due to rocking. The SMA wall demonstrated a larger drift capacity and did not experience crushing of the concrete at the extreme compression fibre as was evident in the steel-reinforced wall. A major difference in the behaviour of the two walls was fracturing of the reinforcement. The reinforcement in the boundary zones of the steel-reinforced wall fractured, whereas the SMA in the boundary zones of the SMA-reinforced wall remained intact.

We.2.A.8 12:15

Retrofitting of Concrete Exterior Beam-Column Joints using NiTi-SMA Sheets

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Deficient reinforced concrete structures exist in large numbers worldwide in the seismic prone regions. The mode of failure in these buildings being predominantly a brittle shear failure at the beam column joints. Several techniques including steel sheets and elements and fiber-reinforced polymers including carbon fiber (CFRP) and glass fiber (GFRP) sheets have been extensively used to strengthen the existing deficient beam column joints in shear. If BCJs can retrieve their predetermined strength and shape after a seismic event, then problems related to collapse and permanent damage, might be solved. Shape memory Alloys (SMAs) are unique alloys and novel functional materials that exhibit small residual strain under loading and unloading cycles even after yielding of the material, in sharp contrast to the normal steel. This material has the capability for remembering its original shape even after a severe deformation. It can undergo large deformations and return to its undeformed shape by heating or on the removal of the stress. SMA in the form of sheets provide one of the possibilities as reinforcement/strengthening of concrete joints. The use of SMA sheets in lieu of CFRP/GFRP and steel sheets in the deficient BCJs has not been explored to the best of our knowledge. BCJs strengthened with SMA sheets can enhance the ductility and load carrying capacity of the joints. It can also preclude development of large cracks, which can render the existing deficient joints irreparable. This paper presents the results of an experimental investigations conducted on BCJs strengthened using SMA sheets. The experimental results showed that SMAs sheets enhanced the ultimate load carrying capacity of retrofitted specimens as well as increased the residual load carrying capacity.

We.2.B | DAMAGE CONTROL, REPAIR AND STRENGTHENING (III)

We.2.B.1 10:30

Thermal modeling for the prediction of the epoxy adhesive service temperature used in CFRP strengthening of RC bridges

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The mechanical response of Carbon Fiber Reinforced Polymer (CFRP) used for the strengthening of reinforced concrete bridges is particularly influenced by the temperature. The epoxy-based adhesives used to bond CFRP to concrete are characterized by the glass transition temperature (Tg), which conventionally marks the transition between the glassy state and the rubbery state (visco-elastic state). To avoid the risk of extensive creep and damages (premature debonding), the service temperature (Ts) should be kept between 10 to 15° C lower than the Tg.
The present study focuses on the determination of the temperature that can occur in the adhesive when CFRP strips are applied to strengthen the top surface of RC bridges. Ongoing experimental tests, which simulate a strengthened lateral cantilever of a RC box girder bridge show, that a service temperature of approximately 40-50°C is likely to be encountered in the adhesive during hot summer days in Dübendorf (near to Zurich, CH); the indicated temperature range depends on the thickness of the asphalt layer. These temperatures are comparable to the Tg values of commercially available adhesives (50-60°C), therefore for this type of applications, an epoxy adhesive with higher Tg is recommended.
A numerical model was developed to predict the temperature of the epoxy adhesive under the asphalt layer. This model is able to take into account the solar radiation and the daily change of air temperature during summer hot days. The numerical model was validated against the experimental results. Finally, a parametric analysis was carried out to analyze how geometry and environmental conditions can affect the adhesive temperature.

We.2.B.2 10:45

Rehabilitation of Mohammed Al-Qassim Bridge after Fire Attack Using CFRP Sheets: A Case Study

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This paper focuses on a case study of Mohammed Al-Qassim Bridged highway that developed extensive damages in main prestressed concrete girders due to a huge fire attack in two successive spans and the adjacent ramp span. This highway bridge consists of 118 spans composite concrete bridge (i.e., precast prestressed concrete girders and cast-in-situ deck slab) is existing in Baghdad city on the main circular express highway. The bridge is 4012 m long, where each span is 34 m long. The importance of this structure from economic and traffic points of view has made it impossible to think of the total replacement. Accordingly, the possibility of the replacement of the three spans was ruled out due to the tedious nature of the process, the time and cost. The main goal of the study was how to restore the original load capacity of the pretensioned girders using CFRP strengthening technique. To achieve this goal, a strengthening system was proposed to the three defected spans by installing a series of CFRP sheets on the soffits and sides of the main prestressed concrete girders. After strengthening, a load test was carried out to verify the strengthening system. Results of the load test and the numerical analysis proved that the proposed strengthening system improved the stress distribution in all components of the bridge and maintained the original load resistance mechanism provided by the prestressed girders and the deck slab.

We.2.B.3 11:00

Influence of FRP Repair on the Axial Behavior of Fire Damaged Concrete

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The exposure of concrete to elevated temperatures detrimentally affects its mechanical properties and thus, efficient repair materials and schemes would be needed to regain these properties. This study reports the results of an experimental work on the influence of fiber reinforced polymer (FRP) repair on the axial stressstrain behavior of concrete cylinders exposed to fire. Within the scope of the study, twelve plain concrete cylinders with dimensions of 150×300 mm were cast. While three of the cylinders were kept in ambient conditions, nine of them were exposed to ISO-834 standard fire for 60 minutes. After natural cooling, i) three of the fire exposed specimens were kept without repair, ii) three of them were repaired by jacketing with two layers of carbon FRP sheets and iii) other three of specimens were jacketed with four layers of FRP sheets. Then, all of the specimens were tested under uniaxial compression. The test results indicated that exposure to elevated temperatures leads to a reduction in compressive strength and modulus of elasticity but an increase in the axial strain corresponding to peak stress for the heated plain specimens. When confined with FRP jackets, the compressive strength and deformation capacity of these fire damaged specimens enhanced remarkably. On the other hand, the repair technique was found to be ineffective on reinstating the axial stiffness of the specimens which was reduced after fire exposure. Furthermore, the prediction performance of a unique model available in the literature that has been proposed for predicting the axial stress- strain behavior of fire damaged FRP confined circular columns was investigated. It was seen that the model did not exhibit a reasonable performance for the specimens tested in this study.

We.2.B.4 11:15

Size Effect of RC Beams Strengthened in Shear with EB CFRP L-Shape Laminates

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In recent years, strengthening of existing reinforced concrete (RC) structures using externally bonded (EB) fiber-reinforced polymer (FRP) has gained popularity. Numerous studies have shown that the size effect is a major parameter that may influence the shear behavior of conventional RC beams. This contrasts with the very few studies dedicated to the size effect of RC beams strengthened in shear with EB FRP. This has been the main impetus to carry out the present study to investigate the influence of size on the shear behavior of RC

T-beams strengthened in shear with EB Carbon FRP (CFRP) L-shape laminates. The experimental program consisted of geometrically similar beam specimens with internal transverse steel reinforcement and having two different effective depths (medium and large size). The tests were conducted on control (unstrengthened) beams and on shear-strengthened beams using EB CFRP L-shape laminates around the web in U-wrap configurations, with and without an anchorage system. The ratios of longitudinal, transverse steel and EB CFRP composites were maintained constant for the two different sizes of RC T-beams considered. The results revealed the presence of a size effect in all the specimens, where both the concrete and the CFRP contributions to the shear resistance were affected, despite the presence of transverse steel. The EB CFRP strengthened specimens with an anchorage system achieved the highest shear resistance gain, but were the most affected by the size effect. For instance, increasing the beams size from medium to large resulted in a shear resistance loss of 16% in strengthened specimens without an anchorage system and 24% in strengthened specimens with an anchorage system.

We.2.B.5 11:30

Study on new strengthening method using a soft layer of poly-urea and prefabricated CFRP plate for the prevention of peel off

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From the past research by the authors, the effectiveness of the construction method in improving bonding performance by using poly-urea resin with the prefabricated CFRP plate in the concrete structures have been confirmed by the shear bond test. This strengthening method has an advantage of labor saving in the construction sites. In this study, RC beam specimens were prepared by using high modulus or high tension type CFRP plate with parameters such as, conventional CFRP plate or prefabricated poly-urea resin CFRP plate, this adhesion method, and were evaluated by the bending test. The result indicate that, we could not confirm improvement of bending reinforcement effect by inserting poly-urea resin using high modulus CFRP plate specimen, but using high tension type poly-urea applied and conventional CFRP plate for RC beam specimen. The maximum load of the prefabrication specimen was about 1.6 times higher than that of the specimen without soft-layer. Therefore, the prefabrication specimen was also obtained sufficient reinforced effect.

We.2.B.6 11:45

Performance of Continuous Concrete Beams with Reinforced FRP Bars and Sheets

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The growing use of fiber-reinforced polymer (FRP) composites has led to the development of new fibers, such as basalt sheets and bars. While basalt has an excellent tensile strength, its external use as sheets can be hindered by debonding. One way to overcome this issue is to replace the normal strength concrete (NSC) with ultra-high-performance fiber-reinforced concrete (UHPFRC), which has superior bond with FRP. However, this material is more expensive than NSC. In the present numerical study partial use of UHPFRC was proposed to investigate the cases of (a) a continuous beam reinforced with carbon, glass, and basalt bars and (b) a steel-reinforced beam strengthened with same fiber types in the form of sheets. A cost analysis was performed to assess the feasibility of each case. The results revealed significant increase in the beams load capacity and successful prevention of debonding at a cost 81% lower than the full use of UHPFRC.

We.2.B.7 12:00

Predicting service life extension and cost due to different repairs on concrete structures under marine environment

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In this study, the service life of repaired concrete structures under marine environment is predicted by considering the mechanism of chloride ion diffusion based on the partial differential equation (PDE) of the Ficks second law. The one-dimensional PDE cannot simply be solved, when those concrete structures are cyclically repaired with two repair strategies; cover replacement or silane treatment. The difficulty is encountered in solving nonlinear chloride ion concentration and space-dependent diffusion coefficient after repairs. In order to remedy the difficulty, the finite difference method is used. By virtue of numerical computation, the nonlinear chloride ion concentration can be treated point-wise. And, based on the Crank-Nicolson scheme, a proper formulation embedded with space-dependent diffusion coefficient can be derived. By using the aforementioned idea, space- and time-dependent chloride ion concentration profiles for concrete structures under diffeent repairs can be determined, and their service life can be predicted in addition to their associated cost. Finally, numerical examples are presented for comparison.

We.2.B.8 12:15

Use of cement based grouts in the rehabilitation of concrete dams: a review

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Grouting is the most common procedure for repairing and reinforcing cracked concrete dams, including the resolution of seepages, as well as for rehabilitation of contraction joints. Grouting is used to both interrupt the deterioration process and increase the structural safety level of the dam.
This document addresses aspects such as assessment of the dams stability, preparatory works, recommended practices, common methodologies and standard precautions concerning the injection of cement based materials for filling cracks in these massive structures. Recommendations and considerations regarding the use of cement grouts as part of the rehabilitation of contraction joints in dams are also presented.
The main features related to the injection itself, including references to grouting materials, equipment and pressures and are also briefly discussed. In this context, a list of successful rehabilitation operation case histories is provided, including a short description regarding the anomalies and their causes as well as the rehabilitation methodology adopted for each situation.

We.2.C | SHM – SMART SENSORS (II)

We.2.C.1 10:30

Optimization of frequency ranges in health monitoring of RC frame using embedded PZT sensors

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The present study experimentally investigates the systematic performance in monitoring the high cycle fatigue damages of Reinforced Concrete (RC) frame structure while implementing the Electro-mechanical Impedance (EMI) technique. PZT transducers embedded in concrete frame in form of ceramic patches has been excited electrically at healthy and damaged states of frame prototype for acquiring mechanical impedance based signature responses in different frequency ranges. For the purpose of optimization, seven different exciting frequencies ranges i.e. 100 kHz – 150 kHz, 150 kHz – 200 kHz, 100 kHz – 200 kHz, 500 kHz – 600 kHz, 600 kHz – 700 kHz, 900 kHz – 1000 kHz, and 20 Hz – 1000 kHz were chosen for obtaining reliable estimation of damage severity due to induced fatigue loads. Signatures variations in form of root mean square deviation (RMSD) and cross-coefficient damage metric (CCDM) for impedance real part, i. e. conductance (G) and as well as for imaginary part i.e. susceptance (B) in user defined frequency ranges has been plotted and compared for different damaged states. Results revealed a successful demonstration in predicting fatigue damage using embedded PZT sensors in frequency range 100 kHz – 200 kHz when compared with other considered frequency ranges. Findings of the present study guide the future researchers and engineers to take concise frequency ranges while monitoring the health of RC structures ultimately saving the procedure time while ensuring effectiveness of PZT transducers in arresting high cycle fatigue damages.

We.2.C.2 10:45

Novel concrete crack detection concept by means of shape memory alloy-based fibers

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Conventionally, non-continuous techniques are used to detect, locate and quantify structural damages on buildings, bridges or other infrastructure. If a structural damage or failure is detected, continuous monitoring by means of conventional sensors is required until refurbishment or demolition. Moreover, early detection in order to avoid sudden collapse is absolutely necessary. Hence, the search for new nondestructive continuous monitoring methods has become increasingly important in recent years. For this purpose, functional materials can pave the way to novel crack detection possibilities. Among them, thermal shape memory alloys (TSMAs) are potential candidates, due to their advantageous mechanical properties.
This paper reports on results of discussions and investigations of an approach for a novel structural health monitoring system in concrete structures: radio frequency network analysis for cracking occurrence detection and localization. Initial investigations were performed using glass fiber reinforced concrete tensile samples with embedded TSMA fibers. At certain crack opening widths, transmission and reflection were measured in frequency domain. The formation of cracks led to a measurably changed propagation behavior of the electromagnetic wave, showing that information about spatial position and geometry of cracks can be determined.

We.2.C.3 11:00

Piezoelectric Wafers Placement Optimization on Tubular Structures – Towards Application on Pipelines

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The integration of Structural Health Monitoring (SHM) systems on our automotive, aerospace and civil structures highly relies on the continuous data collection from the sensor embedded or retrofitted on the structure of interest. The nature of the data, the number, and the locations of sensors significantly affects the performance, robustness and the cost of the SHM system.
This paper presents a model that was developed for optimization of the number and locations of piezoelectric wafers on continuous surfaces of various forms, such as circular, rectangular and square sections. The proposed objective function is to maximize the coverage of the network on the structure, that is discretized to a set of control points, while minimizing the number of PZT wafers. The tubular structure is modelled as a plate of any given dimensions with the appropriate boundary conditions imposed.
In the optimum solution, each control point should be covered by a user-defined number of sensing paths, defined as the coverage level. During the optimization process, any location on the plate is considered as a potential position for a PZT wafer. The algorithm provides the flexibility of changing a wide range of parameters including the number of PZT wafers, the distance covered around the sensing path, the required coverage level and the number of control points. Moreover, since the structure is continuous, the wave can propagate in every direction. Thus, a pair of PZT elements can communicate in two directions and can cover the control points lying in the neighborhood of its two corresponding paths. The tractability of the proposed model was improved by feeding the solver an initial solution. The suggested model was solved using genetic algorithm.
Multiple sensor network configurations were simulated on circular and rectangular tubular structures, and the performance of the optimizer was validated experimentally. The results were very promising and they demonstrated the proficiency of the developed model in distributing the PZT wafers on curved structures.

We.2.C.4 11:15

Existing crack monitoring by distributed optical fiber sensor

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Distributed optical fiber sensor is expected to be one of the best candidates for monitoring on underground repository for radioactive waste, because of its multiplexing ability and long-term durability. Recent development of Brillouin-based sensing can achieve distributed strain information with high spatial resolution. For a field

experiment in a deep underground tunnel, the optical fiber sensor has applied to a mock-up concrete pit, which corresponds to a low diffusion layer. On the surface of the concrete, an optical fiber is attached along the entire length for strain sensing, crossing a couple of the existing cracks. As a result of the year-around measurement, opening displacement of the cracks has detected by distributed strain information. Successfully, Brillouin-based optical fiber can reveal the existing crack behavior, which is that the crack tip slightly opens in the cold and closes in the warm. Such temperature-dependant behavior derived from thermal expansion of concrete, thus the crack tip opening displacement might to be influenced by the size and/or the depth of crack. This study experimentally indicate that distributed optical fiber sensor can not only detect the occurrence of new crack, but also identify the existing crack.

We.2.C.5 11:30

Distributed Fiber Optics Monitoring of the Lago Bianco Dam in Switzerland

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The Lago Bianco dam is a concrete gravity wall, which was built in 1911. The height of the dam was increased from 12 m to 16 m in 1942. Several conventional sensors accurately monitor the dam, including extensometers, piezometers, thermocouples, joint meters, GPS and geodetic instruments. Although the already existing sensors are adequate for monitoring the dam, an additional distributed fiber optics monitoring sensor system (DFOS) has been installed: The main goal was to verify the measurements of the conventional sensors, in particular strain, temperature and concrete crack development but with significantly higher spatial resolution. The DFOS were installed in a two dimensional grid on the downstream side of the dam and it was interrogated for more than four months on different time intervals. The DFOS enabled accurate and precise distributed measurements of the variation of temperature and strain of the dam surface. The collected data are in good agreement with the local measurements of the conventional sensors. Additionally, the DFOS allow for a more comprehensive understanding of the dam mechanical behaviour.

We.2.C.6 11:45

Assessment of crack patterns along plain concrete tunnel linings using distributed fiber optic sensing

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The acquisition of the crack patterns along plain concrete tunnel linings requires extensive manual effort, especially in the secondary lining behind the tunnel cladding. Existing automated monitoring techniques are often limited in the spatial resolution and insufficiently reliable, why new sensing reliable methods are needed to capture crack patterns without any line-of-sight to the surface of the tunnel lining.
In this paper, we introduce a distributed fiber optic sensing approach for crack monitoring along concrete tunnel linings. The designed setup allows strain measurements with a very high precision of about 1µm/m every 10 millimeters or even better. This high spatial resolution enables the identification of local damages, like cracks in the structure. Moreover, the effective crack width can be derived from the distributed strain profiles, which however requires the calibration of the sensing system under well-known conditions. Various laboratory test series were carried out in advance to the tunnel application, in which different sensing setups were installed along the surface of concrete beams and investigated under different known loading conditions (initial cracking, variation of crack width under different loads, fatigue test simulations). Verification measurements using electric displacement sensors as well as manual optical readings were used to calibrate the measured strain profiles at defined positions and to derive the true crack width. This paper summarizes the results of these investigations, including a comparison between different optical fibers as well as different adhesive types for sensor installation on concrete surfaces. The outcomes demonstrate the high potential of distributed fiber optic sensors and their capability to extend or even to supersede traditional approaches for structural monitoring.

We.2.C.7 12:00

Monitoring high thermal performance concrete for concentrated solar power plants with fiber optic sensors

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In this paper a monitoring system for concrete structures at high temperatures (500ºC) is presented. The aim of the monitoring strategy based on fibre optic sensors (FOS) is to develop a high-tech monitoring technology for future installation in Concentrated Solar Power (CSP) plants with the purpose of lifecycle analysis and predictive maintenance via structural health monitoring (SHM). The monitoring strategy is based on embedding FOS in high thermal performance concrete while it is casting. The FOS technology employed to monitor both temperature and strain in concrete is known as Fibre Bragg Grating (FBG). In this work, the development of the special metallic coating and smart packaging employed to protect the sensors in this harsh environment, the calibration of the sensors and the thermal validation of the monitoring system at lab scale working in a range of temperatures between 200ºC and 500ºC is demonstrated. The lab tests were performed over a sample of 30x30x30cm, composed of 2 different layers and 4 tubes of steel, the core is made with concrete specially manufactured to have a very good thermal behaviour, and the second layer is for the insulating, and it is formed by foam concrete. The FBG sensors were positioned longitudinally, parallel to the tubes by drill holes on the casting structure at 14 different positions. The concrete curing process and some different heating cycles up to 500ºC, simulating the thermal behaviour of CSP plants, were monitored using the fibre sensors.

We.2.C.8 12:15

Static load monitoring of a concrete bridge using a high-precision distributed fiber optic sensor system

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In the present study, the impact of static traffic loading on the slight deflection effects in the concrete structure of an existing bridge has

been investigated using distributed fiber optic sensors. The results of the load tests on the Amsterdam bridge 705 make an important contribution to the understanding of its structural behavior. The evaluated data can be used to support and verify finite element models contributing to ensure the safety of the ageing concrete structure of the bridge. In the face of increasing traffic density and severe traffic loading, the safety evaluation based on accurate distributed fiber optic measurements can be an important means of increasing the lifetime of the bridge. The concept of the static loading was based on the use of two 36-ton trucks stopped on the bridge at multiple pre-determined locations. The load applied in this way led to location-dependent small deflection effects recorded as longitudinal strain of the sensing fiber embedded at the underside of the bridge. The laying of the 96-m long sensing fiber in one piece across and along the bridge serves to obtain distributed two-dimensional sensor data. The application-specific sensor configuration used here facilitates also the filtering of the temperature component in the measurement signal. The achieved results demonstrate the capability of the applied system and method to detect minuscule elastic strain in the range of a few µm/m at the spatial resolution of 20 cm along the 96-m long sensing fiber. The measurements were performed with a commercially-available solution using Tunable Wavelength Coherent Optical Time Domain Reflectometry (TW-COTDR). In the TW-COTDR method a tunable laser diode is used to generate power spectrum of the Rayleigh backscattered light as a function of the performed frequency scan. The frequency shift giving information about strain and temperature changes can be finally calculated by comparing two measurement via cross-correlation. The results of such relative measurements showed accuracy in the range of 0.5 µm/m. The measurement performance allows conclusions to be drawn about the residual strain distribution along the sensing fiber caused by the various loading steps.

We.2.D | NON-DESTRUCTIVE TESTING IN CIVIL ENGINEERING (II)

We.2.D.1 10:30

Quantification of digital image correlation applicability related to in-situ proof load testing of bridges

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Advanced crack monitoring is crucial for high precision response- and threshold evaluation when performing proof- and diagnostic load tests on existing concrete structures. Mostly, crack monitoring techniques involve one monitoring method, which provide thresholds with regard to stop criteria and characterization information. In the ongoing Danish bridge testing research program, it is hypothesized that several independent monitoring techniques are needed to reduce uncertainties related to crack detection and categorization. A number of novel monitoring methods are used in the research project. A special focus is however dedicated to two-dimensional digital image correlation (2D-DIC) and acoustic emission (AE). This paper presents initial research concerning evaluations related to digital image correlation based on sub-component beam tests performed in the DTU CasMat laboratory facility. The tested beams were prefabricated as TT-elements with a length of 6.4 m and cut into two T-beam elements. The test matrix consisted of ten beams strengthened with carbon fiber reinforced polymer (CFRP) in different configurations with and without post-tensioning of the CFRP, thus resulting in different crack initiation behavior. The investigations in this paper include: (1) time of crack detection compared to visual detection, (2) time of crack detection compared to time of crack width threshold values, and (3) crack width evaluation using 2D-DIC strain correction for out-of-plane deflection. The results show that cracks can be detected prior to both visual detection and significant stiffness change. After detection, crack development can be monitored for crack width stop criteria. Crack widths can also be successfully monitored for surfaces subjected to out-of-plane movement using a geometric correction method. The methodology is hypothesized to be of significant importance in future testing of full-scale concrete slab bridges in the Danish bridge testing project.

We.2.D.2 10:45

A Feasibility Study of Laser-based Concrete Stress Measurement Technique

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In this paper, a feasibility study for a laser-based concrete stress measurement technique has been conducted and experimentally validated with uniaxial compression tests. Photoluminescence piezospectroscopy (PLPS) method is widely used for measuring residual stresses in thermal barrier coating, and the technique is being researched in civil engineering field recently thanks to its laser-based non-contact and non-destructive features. However, its feasibility has been only validated for metal-based materials. For example, by coating a metal material with a piezospectroscopic material, the stresses in the metal material can be measured. In this paper, non-contact and non-destructive PLPS technique is firstly applied to a concrete material for measuring its stress. To do that, a piezospectroscopic material has been mixed with cement powder, and cubic specimens have been fabricated for uniaxial compression tests. Based on the uniaxial compression tests, it has been experimentally proved that the applied compressive stress into the specimen and its spectral peak shift have a linear relationship.

We.2.D.3 11:00

Monitoring a concrete bridge girder with the coda wave interferometry method

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Concrete bridges play an important role in the construction of urban infrastructure. Environmental factors and excessive use accelerate the aging of bridges. The collapse of bridges can cause casualties and serious economic losses. Hence, more and more people realize the necessity of structural health monitoring. Coda Wave Interferometry (CWI) technique for ultrasonic data is considered as one of the most promising methods to monitor concrete structures due to its high sensitivity to weak perturbations in a heterogeneous medium. Large structures can be monitored using a limited number of

sensors. Previous research has shown that CWI successfully detects temperature and stress changes in laboratory size concrete specimens. However, up to now, because of the complexity of the outdoor environment, CWI technique hasn't been implemented on any real bridges. In this paper, a 36 meters long bridge girder in Gliwice, Poland instrumented with different types of sensors (embedded ultrasonic sensor, strain gauges and thermocouple) inside the middle part will be studied. The bridge was monitored for 5 days. For preliminary evaluation, the influence of traffic and temperature could be detected and future improvement for long term monitoring could be discussed and planned.

We.2.D.4 11:15

Continuous Acoustic Monitoring of a Prestressed Concrete Bridge in Germany

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The networks of the german road and railway administrations still contain a significant number of bridges manufactured with steel endangered by stress corrosion cracking. These bridges were mostly built in the first half of the 20th century, when the construction method was in a rapid development, so that the lack of experience and rules led to various deficits. In this case, an ongoing corrosion process can lead to the failure of the prestessing steel and therewith the loss of the structural safety.
On this occasion, specific guidelines were published, that provide computational and material assessment of these structures. In many cases, however, the recommended methods do not lead to a (desired) result and the final definition of appropriate measures. One central problem is the poor inspectability of the tendons condition. In this context permanent monitoring has played a subordinate role, even though the degradation processes and their consequences occurring in the structure can be excellently resolved and the continuous information gives the possibility to state the condition of the structure at any time. Based on a practical application, a 102 m long prestressed concrete bridge, the article discusses the limits of current guidelines and presents the application of an acoustic emission monitoring as an alternative approach. Firstly the results from basic scientific investigations (e.g. coupling of sensors) and the conceptual design of the measurement layout are presented. Furthermore, important results from the commissioning measurements (artificial wire breaks at the structure) and the first months of continuous measurement are discussed.

We.2.D.5 11:30

Magnetic measurement of corrosion in a steel structure using extremely low-frequency eddy current testing without surface treatment

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Several concerns with regard to long-term safety and maintenance are involved in civil engineering structures that have aged and deteriorated. Many of these structures are made of steel and are prone to corrosion. Corrosion causes thinning of these structures, which in turn reduces the structures durability. Corrosion occurs not only on the surface but also inside the structure. Ultrasonic testing is commonly used to detect the thickness of the corroded steel. However, surface treatment is required to remove the rust or paint for ultrasonic testing. Surface treatment requires a long time, which makes it difficult to inspect the wide area of the structure. We previously reported an extremely low-frequency eddy current testing (ELECT) method to detect the thickness of steel. In this study, our developed ELECT device was applied for field testing and we evaluated the influence of rust and paint. In particular, we evaluated the influence of lift-off variations caused by the severe corrosion of a thick and laminated structure. By magnetic spectrum analysis using multiple frequencies from 1 Hz to 1 kHz, we measured the thickness of steel was measured to be within 20 mm; this portion was not affected by rust and paint. The signal fluctuation caused by lift-off variations was also corrected by magnetic spectrum analysis. Therefore, we obtained the same estimated thickness from the surface as well as from the measurements on the inside of the structure. The proposed ELECT method does not require surface treatment and is capable of realizing rapid inspections for applications in large civil infrastructure.

We.2.D.6 11:45

Update of Service Life Design with Monitoring Data from Corrosion Sensors

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For reinforced concrete structures exposed to severe environmental impact monitoring becomes more and more important. With the information achieved by monitoring the actual deterioration progress can be determined. Furthermore, the remaining service life can be identified by implementing the evaluated monitoring data into a full-probabilistic service life design. As a consequence, the integration of monitoring data into service life design has become an important optimization tool for intervention and maintenance strategies. This is crucial for both owners and engineers as budgets for maintenance and repair action are usually very limited.
In this paper a case study is presented in which data from corrosion sensors (in this case Anode Ladders) installed into parking decks of a major parking garage is being used to update the a-priori service life design with respect to chloride-induced reinforcement corrosion. Chloride-induced corrosion is in most cases the governing deterioration process for parking structures and of high economical relevance as consequences can be costly. During the design stage both the environmental impact and the material resistances are unknown and will thus be incorporated with correspondingly high variation coefficients, leading to a great extent of uncertainty for the a-priori design. Integration of monitoring data during the use of the structure by means of a Bayesian Update will lead to a deeper understanding of the structural condition and gradually to a higher degree of certainty of the service life design and thus enable the owner to schedule the optimal point-of-time for intervention measures.

We.2.D.7 12:00

Vibration based Condition Assessment of Deteriorated Reinforced Concrete

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The commonly used electrical resistivity based methods are beneficial to estimate the mass loss of the reinforcement. However, it is also possible to estimate overall deterioration caused by corrosion in the reinforced concrete (RC) elements by using vibration based methods. In the conventional vibration tests, the condition assessment is mostly based on monitoring the changes in the modal frequencies, which may not provide an objective interpretation in all cases. Instead, monitoring the nonlinear behavior in the dynamic response of the structural elements may serve better for the purpose of assessment of structural integrity. Herein, a diagnostic feature which represents the significance of non-linearity in the response vibration of the structural elements is discussed. This feature quantifies the severity of damage by measuring the magnitudes of higher harmonics of fundamental modes existing due to the damage in the element. In this paper, an adaptive higher order spectral analysis method is demonstrated on the simulated data in order to detect and quantify the non-linearity, and hence the structural damage. This study is planned to be extended to experimental works on the lab-scale RC columns with varying corrosion conditions.

We.2.D.8 12:15

Structural health monitoring of Artemio Franchi Stadium in Florence, Italy: measurement using interferometric radar

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The Artemio Franchi Stadium in Florence, Italy, designed by Pier Luigi Nervi in 1929, was built from 1930 to 1932. The stadium has a reinforced concrete structure and it is composed by 24 stands, a 70-meter tower (Maratona tower) and a cantilever roof covering the grandstand in the opposite side to the tower. In occasion of the World Cup in 1990 the stadium was renovated by adding seats at the ground level as retrofit. A study for seismic requalification is in progress and an interferometric radar has been used for monitoring the architectural complex. In particular, the radar monitored the Maratona tower and some of the stands. In this paper, the experimental results of this preliminary measurement campaign are reported. The interferometric radar is a remote sensor for monitoring large structures. When the structure under test is excited by external actions (i.e. wind, vehicular traffic, vibrodyne), the interferometric radar is able to detect the displacements of the structure and to measure its natural frequencies. For testing the Maratona tower also the wind action was exploited. The measurement of its natural frequencies was performed both with an interferometric radar and a seismic accelerometer. The radar was installed in two different position (on the playground and close to an entrance of stadium), the seismic accelerometer was installed on the towers attic. Natural frequencies measured with both instruments substantially match. The experimental results have been then utilized in order to define a finite element computational model for the simulation of the dynamic response of the tower and stands. This phase of the research is still in progress requiring the better definition of the constraints especially at the base of the tower, considering for it also the presence of the gym and swimming pool placed at its underground.
The stands are too rigid to be appreciably excited by wind or vehicular traffic, hence the measurements were performed during football matches. The supporters movements were used as input action to measure the dynamic properties of stands. Unfortunately this input was not enough wide to allow the measurement of the natural frequencies of all the stands.

We.3.A | STRENGTHENING, MONITORING AND LIFE-CYCLE ASSESSMENT OF METALLIC STRUCTURES (I)

We.3.A.1 14:00

Adhesively Bonded CFRP Composites for Steel Strengthening: An overview

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Adhesively bonded joints are commonly used for carbon-fibre reinforced polymer (CFRP) strengthening of concrete structures. There are a relatively large number of studies on different aspects of the CFRP-to-concrete bonded joints, however, this is not the case for bonded joints used for the strengthening of steel structures. Long-term performance and uncertainty related to environmental durability are critical barriers for the wide applications of bonded joints in structural applications. Moisture and temperature and their combined effect on both constituent material and system levels are identified as the most critical environmental factors. There is a need for studies that address short- and long-term structural behavior of the CFRP-to-steel bonded joints. This study aims to provide a review on the most recent works and studies on the CFRP-to-steel bonded joints conducted by different active research groups in Switzerland, China, Sweden and Australia. Finally, some recommendations for future studies in this topic will be provided.

We.3.A.2 14:15

Simplified FE model predicting the bending behaviour of corroded tubular steel members rehabilitated using CFRP

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Offshore structural members will be forced to undergo repair and strengthening when either the structural components have degraded critically due to the corrosive marine environment or the structure needs to carry extra loads than they were designed for due to work over demands, heavier equipment or increased environmental loads. Using FRP composites is established as a cost-effective and

efficient method for rehabilitation and non-structural repair of these type of structures. However, the use of FRP composite material in strengthening or structural repair of offshore facilities is still limited to a few basic applications due to the lack of a proper design framework. Tubular steel members are widely used in offshore platforms and in this paper, existing experimental test data for the ultimate strength of tubular sections retrofitted with CFRP under bending was used to develop an FE model. The accuracy of the model was examined against the experimental data and a reasonable match was found. The simplified FE modelling technique presented in the paper is expected to aid in the development of a design framework for CFRP retrofitted steel tubular members.

We.3.A.3 14:30

Added value of regular in-service visual inspection to the fatigue reliability of structural details in steel bridges

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In order to design structural details of bridges for fatigue, the current version of the Eurocode for steel structures recommends partial factors for fatigue resistance based on the consequences of failure and on the maintenance method. The safe-life method is used for details where local formation of cracks could rapidly lead to failure or for details not accessible for inspection and has a relatively high partial factor. The damage tolerant method, on the other hand, is used for cases where fatigue crack initiation does not result in immediate failure so inspection and repair can be performed. In the current Eurocode, this comes with a relatively low partial factor. However, since the probability of crack detection of visual inspection by the naked eye is considerably different from more detailed inspection methods, the required partial factor to design a bridge for fatigue should be based on the way and level of inspection planned during the bridge service life. As a common practice, for most bridges, only visual inspections in short time intervals are carried out. In this paper, the added value of periodic visual inspection on the reliability status of a steel railway bridge is studied. The probability of failure after performing visual inspection is investigated by two approaches: 1) A statistical study on the main causes of bridge failure carried out by other researchers to find the relation between the safe-life design method and the design method considering visual inspection; 2) Conducting a survey to collect experts opinions on the matter and using a Bayesian algorithm to assign a probability distribution function to each opinion. A relation between reliability indices for the cases where a bridge is designed with and without considering the in-service visual inspection, is derived.

We.3.A.4 14:45

Local and Distortional Buckling Behaviour of Cold-Formed Steel Sigma Beam-Column Profiles

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Cold-formed steel (CFS) sigma profiles generally used as purlins or portal frame members are shown in the literature to exhibit higher load carrying capacities compared to standard channel section profiles. However, currently CFS channel sections are more widely used, especially in residential buildings, due to ease of installation and also the knowledge about their structural performance gained through numerous experimental and numerical studies over last decades. To bridge the knowledge gap in using CFS sigma beam-column sections in common practice, this study aims to investigate the characteristic behaviour of these elements including their stiffness and strength under axial load and biaxial bending. In general, to determine the capacity of beam-column members, most existing design guidelines (e.g. AISI S213-07, AISI S100-12, AS/NZS 2005) suggest closed formed interaction formulas as a linear combination of axial load, and strong- and weak-axis bending moment effects. However, this approach ignores the nonlinear interactions between these actions. To address this issue, in this study, the structural behaviour of eccentrically loaded beam-column elements with CFS sigma profiles is investigated under simultaneous effects of axial loads and strong-and weak-axis bending (P-Mx-My). To this end, CUFSM software is used to determine the dominant buckling mode (i. e. local, distortional or global) and load carrying capacity of CFS sigma beam-column elements with different lengths. Material parameters are also implemented in the detailed finite element models developed in ABAQUS software. The models are then used to estimate the strength and buckling behaviour under monotonic loadings. A total of 315 finite element analyses are performed on different CFS beam-column elements with sigma profile and the results are compared with existing codes.

We.3.A.5 15:00

Strength of concrete with FRP fabric confinement using geopolymer bonding agent after exposure to high temperature

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Epoxy based bonding agents have been commercially developed for effective bonding of FRP with concrete for strengthening purposes. However, epoxy resins usually show loss of strength and stiffness at high temperature. This paper presents a study on the comparison of strengths of concrete cylinders confined by basalt fibre reinforced polymer (BFRP) fabrics bonded by an epoxy based agent and fly ash geopolymer. Concrete cylinders were wrapped by two layers of basalt fabric and tested for compressive strength after exposures to temperatures of 65 oC to 350 oC. The mean unconfined compressive strength of concrete cylinders was 40 MPa and the confined compressive strengths increased by 25% and 17% for using epoxy and geopolymer bonding, respectively. Both the bonding agents retained the enhanced strengths after heating the specimens at 65 oC for 90 minutes. After exposure to 150 oC, strength enhancement of the specimens using epoxy bonding decreased to 10% with slight further decreases for the increase of temperature up to 350 oC. On the other hand, the strength enhancement remained almost same for using geopolymer bonding agent for up to 350 oC exposure. Failure occurred by tearing of the fabric in both cases. The reduction of strength enhancement in the epoxy bonded specimens is attributed to the thermo-oxidative degradation of the epoxy resin.

We.3.A.6 15:15

Damage experiment on a steel plate girder bridge and local damage detection utilizing traffic-induced vibration

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This study is intended to investigate feasibility of detecting local damage on a steel plate girder bridge utilizing traffic-induced vibration of the bridge. A field damage experiment on the bridge was conducted, and acceleration responses of the bridge under a single moving vehicle were monitored and utilized for the damage detection. Fatigue cracks observed in actual steel plate girder bridges were considered as local damage, and artificial cracks were applied to the lower flange and web plate near base plate of shoe in the damage experiment. This study investigates changes in the frequencies due to the local damage. A damage sensitive feature from system matrix is introduced, and feasibility of detecting local damage by means of Bayesian inference is examined. Observations showed that frequency of the 1st bending mode increased due to artificial damage though frequencies of the 2nd bending mode and the 3rd bending mode decreased. Generally, it is expected that the natural frequency of bridges will decrease due to damage for damage leads to decrease of bending stiffness. Changes in boundary condition due to damage are considered to examine the mechanism of increasing the frequency of the first bending mode while those of the second and third bending modes decrease. A sensitivity analysis considering influences of changes in rigidity and boundary condition due to damage is conducted. The sensitivity analysis demonstrated that the first bending mode was more sensitive to changes in the boundary condition than change in flexural stiffness so as to show increase of the first bending frequency due to the damage. The proposed Bayes factor as a damage sensitive feature successfully detected anomaly event due to the local damage on lower flange and web plate near base plate of the shoe.

We.3.A.7 15:30

Fatigue performance and evaluation of horizontal gusset plate web gap details in steel bridges

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Full-scale I-shaped steel girder specimens were designed for distortion-induced fatigue mechanism tests of horizontal gusset plate web gaps in steel bridges. The fatigue cracks at stiffener-to-web welds usually initiated at the web gaps, and propagated along the weld towards the weld ends. The fatigue test results indicate that the stress ratio has a significant impact on the distortion-induced fatigue performance of web gaps. Under the action of high stress ratio, the fatigue crack growth rate and the stress reduction speed increases. And the fatigue strength of the stiffener-to-web welds decreases significantly with the increase of the stress ratio. The fatigue strength of stiffener-to-web welds corresponds to category C of AASHTO Specification and category 125 of Eurocode when the stress ratio is less than 0.3, while it belongs to the category E of AASHTO Specification and category 71 of Eurocode when the stress ratio is larger than 0.3 and smaller than 0.5.

We.3.B | DAMAGE CONTROL, REPAIR AND STRENGTHENING (IV)

We.3.B.1 14:00

Development of Numerical Models for Deep Beams with Discontinuity Regions Strengthened by NSM-CFRP

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Numerical finite element (FE) models were developed to predict the load carrying capacity of three reinforced concrete (RC) deep beams. One beam was solid and two beams contained discontinuity regions in the form of a square opening located in the middle of the shear span. One of the beams with discontinuity regions was strengthened with near-surface-mounted carbon fiber-reinforced polymer (NSM-CFRP) composites. The strut-and-tie modeling (STM) procedure was employed to develop a strengthening scheme around regions of discontinuity. Several parameters were investigated during the development of the numerical model including the mesh size, concrete material constitutive law, and inclusion of a bond-slip law for the NSM-CFRP reinforcement. Numerical predictions were very sensitive to the mesh size and concrete material constitutive law adopted in the analysis. Strength results of FE models with and without a bond-slip law at the interface between the concrete and NSM-CFRP reinforcement were insignificantly different. The strengthening scheme fully restored the original shear capacity of the beam. The accuracy of the developed FE models was examined by comparing numerical predictions with those obtained from experimental tests.

We.3.B.2 14:15

EBROG method to strengthen heat-damaged concrete with CFRP sheets

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Externally bonded reinforcement on groove (EBROG) method is recently becoming more popular for strengthening concrete structures with fiber reinforced polymer (FRP) composites. Its capability to increase the bond strength of FRP to concrete substrate and to postpone debonding of FRP, has made it an appropriate substitute to conventional externally bonded reinforcement (EBR) method. Concrete structures in some industrial constructions such as steel companies may be exposed to high temperatures during their lifetime. FRP composites can be used for strengthening heat-damaged concrete in such structures. However, bond properties of FRP to heat-damaged concrete should be investigated. In the current research, EBROG method is used to study the bond behavior of FRP to heat-damaged concrete substrate. To do this, concrete blocks were first subjected to different temperatures of 300, 400 and 500C or maintained in room temperature (25C). They were then strengthened with carbon FRP sheets using EBR and EBROG methods. Eight single lap-shear tests were conducted. 2D Digital Image Correlation (DIC) measurement system was utilized to measure full-field displacements. Experimental results showed that although the concrete strength decreased when subjected to high temperatures, bond strength of heat-damaged concrete strengthened with EBROG method increased significantly compared to those of EBR joints

that were maintained in room temperature. A two-fold increase was observed experimentally for EBROG joints. Heat-damaged EBROG joints experienced a bilinear behavior in terms of load-slip diagrams and reached high slips at final stage.

We.3.B.3 14:30

Assessment of load transfer length in textile reinforced cementitious matrix composites

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Given their mechanical, environmental an aesthetical properties, textile reinforced cementitious matrix composites (TRCMC) are used on a large scale for the rehabilitation and reinforcement of built heritage and civil engineering structures. The effects of the internal mechanical parameters, such as load transfer mechanisms, fibre-matrix interaction, on the overall behavior are deduced combining surface strain measurements and approaches of continuum mechanics taking into account damage and fracture characteristics. Direct measurement of such a kind of internal parameters (load transfer and crack initiation mechanisms, effective load distribution between components) it is still of major scientific interest.
This paper discusses one of the micromechanical parameters that govern the behavior of TRCMC under tensile load. Optical fibres, having a millimetric space resolution, using Rayleigh backscattering principle, were used as linear strain sensors into the core of the TRCMC composite, to measure the load transfer length between the textile and the matrix during uncracked and cracked stages of the composite behaviour.
Two reinforcement ratios were studied: TRCMC with a single layer of textile reinforcement, and with three layers of reinforcement. Therefore, it was possible to establish a general relationship between this ratio and the load transfer length.
Finally, a comparison between the experimental results and existing models was made, which allowed hypotheses and approaches of continuum mechanics to be analysed and adapted.

We.3.B.4 14:45

Rocking concrete shear walls with self-centring friction dampers for seismic protection of building structures

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Ductile concrete shear walls are suitable for protecting buildings from collapse. However, a high level of damage is expected after moderate to severe earthquakes. Low damage design concepts can be considered as an efficient alternative to traditional high damage design to minimize damage so that buildings could be reoccupied quickly with minimal business interruption and repair costs. Rocking wall structures absorb and dissipate seismic input energy during their rocking motion. However, this rocking motion should be controlled by a set of additional systems in which high initial stiffness, damping, and self-centering are provided. Axial and Rotational Resilient Slip-Friction Joint (RSFJ) are technologies in which seismic damage avoidant characteristics are provided. Damage free energy dissipation and self-centring capability have made these compact connections a suitable alternative for current ductile and low-damage solutions. In this paper, the seismic performance of rocking concrete shear walls is assessed analytically and experimentally using these two innovative structural connections. Firstly, analytical and experimental and numerical studies are carried out in order to verify the performance of the connections. Secondly, a simple structural configuration is introduced to apply these connections.

We.3.B.5 15:00

Effect of Internal and External Reinforcement Ratios on RC Beams Strengthened with NSM Prestressed Fiber Reinforced Polymer Rods

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In recent years numerous investigations have been conducted on strengthening of reinforced concrete (RC) beams using fiber reinforced polymer (FRP) bars or sheets. However, the studies on the application of varying FRP prestressing are sparse. The present finite element analysis (FEA) study involves flexural strengthening of RC beams with near surface mounted (NSM) pre-stressed carbon fiber reinforced polymers (CFRP). The FEA beam model was first validated using the data from an existing experimental study in the literature. The beam model had a good agreement with the experimental results. Parameters considered were internal steel and external CFRP reinforcement ratios of the RC beams under 0 %, 20%, 30%, and 40% pre-stressing levels. The finite element results revealed that for all CFRP reinforcement ratios, the 30% pre-stressing level showed significant ultimate load and considerable ductility. The increase in pre-stressing level of CFRP up to 30% resulted in higher load capacity for all steel reinforcement ratios.

We.3.B.6 15:15

FE-Modelling Techniques for Structural Capacity Assessment of Corroded Reinforced Concrete Structures

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About 80% of the observed damage in existing concrete structures is related to reinforcement corrosion. Typical corrosion-associated phenomena that affect the structural capacity concern: (i) cross-section and ductility reduction of steel, (ii) concrete cracking, (iii) concrete area reduction due to spalling and (iv) modification of the bond properties. A number of models have been presented in recent years addressing these issues. The paper presents a critical review of such models and its application to the analysis of corroded RC members using nonlinear FEA. The accuracy of different modelling approaches is assessed through comparison with experimental results on corroded beams subjected to monotonic loading. The selected test cases showed a variety of failure modes, such as flexure, shear and pull-out failures. In addition, some sensitivity studies are also performed in order to gain better understanding of the contribution of each phenomenon. Final recommendations are given for reliable capacity assessment of existing structures affected by corrosion.

We.3.B.7 15:30

Structural upgrading of the longest and skewed span of the Yverdon Viaduct

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The Yverdon Viaduct, built in 1983 and situated in the canton of Vaud, Switzerland, is the object of a refurbishing project aiming to guarantee its remaining service life. The consulting office DIC s. a. ingénieurs in Aigle (Switzerland) was mandated in 2014 by the Swiss Federal Roads Office (FEDRO) to propose a strengthening intervention of the longest and skewed span (73.70 m) of this Viaduct. This span underwent the consequences of a conceptual default (insufficient prestressing) which led to important deformations and appearance of cracks at the lower slab of the multicellular box deck.
Three alternative strengthening solutions were proposed. Two of them were discarded, despite their superior static efficiency, due to the particular constraints of the roads authority.
The conceptual design proposes the implementation of ten post-tensioning cables inside the second and the fourth cell of the concerned span. The post-tensioning cables have a rectilinear geometry and their ends are fixed at the existing skewed crossbeams of the spans edges. New skewed crossbeams (diaphragms) made from self-compacting concrete where cast in place at a distance equal to one third of the span from each edge and serve as deviators of the cable forces.
This article presents all steps of an interesting real case study, from conceptual design of variants up to the execution phase. It shows how simple engineering concepts can be both very efficient and adapted to the numerous restraints as well. Particular attention is paid to modelling as well as to experience obtained from execution from which important lessons can be derived for both the engineering community and the authorities.

We.3.B.8 15:45

FRP vs FRCM in flexural strengthening of masonry

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In recent years giant progress has been made in the understanding of structural behaviour and the development of proficient intervention strategies on existing masonry structures. The retrofit using compatible and efficient structural strengthening techniques was investigated primarily considering new technologies based on Fiber Reinforced Polymers (FRP), i. e. fibres with an organic resin matrix. Lot of knowledge was developed, mainly based on the assumption of linear elasticity for FRP. However nowadays resin matrix has been substituted by inorganic mortar matrices, yielding to the family of Fiber Reinforced Cementitious Matrix (FRCM) systems. Mortar matrix is more compatible with masonry, however FRCM does not behave like as FRP because the matrix cracks before fibre rupture and the contribution of matrix (in terms of stiffness in particular) is not negligible as it is for the resin, hence linear behaviour is substituted by a bi- or even tri-linear behaviour. The easiest way was to extend the models for FRP to FRCM, however it has never been clarified the impact of peculiar behaviour of FRCM on the analyses conducted assuming FRP, i.e. fiber only, behaviour and no compressive strength. The main aim of this study is to develop a general model for flexural behaviour of FRCM strengthened masonry based on dimensionless analysis. In fact, being independent on the geometrical and mechanical parameters of the masonry and of the strengthening system, the results represent the basis for the development of standardized design and / or verification methodologies. In particular it is remarked the impact of different local behaviours of FRCM (and FRP for comparison purposes) materials on the global flexural response of strengthened masonry.

We.3.C | PERFORMANCE AND DAMAGE ASSESSMENT

We.3.C.1 14:00

Detection of bolt loosening through ultrasonic imaging

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Maintaining adequate bolt torque levels is imperative to ensure the integrity of bolted structures. While in operation, the strength of bolted joints is affected due to structural vibration induced bolt loosening. This article reports a non-destructive methodology to detect bolt loosening. An ultrasonic wave based methodology has been used in this study. Piezo electric ceramic patches have been used for the transmission and reception of ultrasonic signals. The investigation of a single bolted joint steel plates tightened at different torque levels have been undertaken in this study. Ultrasonic waves are excited on the steel plate and its interaction with the bolted interface (plate to plate) has been investigated. It is observed that the strength of reflected signal from the bolted interface varies with the level of bolt tightening. These reflected signals are used as inputs for a newly developed imaging algorithm. It is observed that the developed images clearly discerned the loosened bolt from the tightened one. This proposed method is reference free and has potential for the monitoring of a multi-bolt structure non-invasively.

We.3.C.2 14:15

Duration-based Forecasting of Bridge Condition with Non-Parametric Kaplan-Meier Survival Functions

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Duration-based multivariate bridge deterioration models were recently developed based on the statewide National Bridge Inventory (NBI) data of North Carolina in the United States, using a combination of the Cox Proportional Hazards survival analysis and non-homogeneous Markov chain theory. Additionally, simplified models were also developed where bridge condition rating transition probabilities were derived from non-parametric Kaplan-Meier survival functions and implemented in a stationary Markov chain to predict future bridge condition ratings. This paper presents a comparison of the two approaches with the objective of evaluating the relative benefits and limitations of using the empirical Kaplan-Meier estimator instead of the more comprehensive Proportional Hazards model (PHM) based on sample subsets of the North Carolina state bridge inventory. It is observed that the semi-parametric PHM model offers a better statistical fit and is valuable in objectively quantifying the

effect of explanatory factors on bridge deterioration rates. However, the comparison performed on the bridge inventory subset suggests that it does not necessarily result in improved bridge condition forecasting compared to the Kaplan-Meier model. It is postulated that the similar predictive performance of the models can most likely be attributed to the coarse granularity of the NBI general condition ratings. This finding is significant since the reduced data processing associated with the Kaplan-Meier approach may prove useful in expeditious development of duration-based probabilistic deterioration models for extremely large bridge databases.

We.3.C.3 14:30

Performance Assessment of Transversely Stressed Deck Unit Bridges with Damaged Transversely Stressing Bars through Field Measurements

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Load testing was conducted on a decommissioned deck unit (DU) bridge span in Queensland, Australia, to investigate the effects of defective transverse stressing bars (TSB) on bridge performance under live loads. The 16 metre simply-supported bridge span tested consisted of multiple adjacent precast prestressed deck units (voided planks) sitting on concrete portal frame piers. The span was constructed by installing the DUs next to each other, filling the gaps between them with grout and tying them laterally with 29 mm diameter prestressed TSBs at every 2.0 metres along the span. A typical 80 mm thick asphalt wearing surface was laid directly on top of the DUs. For this type of bridge, the load transfer mechanism between the DUs has not been fully understood and accurately quantified due to the presence of the upstanding stiff edge beam, the mortar joints between DUs (no shear-keys), and a low level of transverse stressing. It is, therefore challenging to accurately estimate the capacity of the bridge, particularly when some TSB are damaged (e.g. due to corrosion, missing in construction, or removed during a bridge rehabilitation process).
In this investigation, different levels of damage were introduced to the TSB by severing the TSB at various locations throughout the bridge deck. In each damage stage, the response of the bridge span (strain and deflection) was measured while a 62.5 tonne semi-trailer test vehicle travelled back and forth across the bridge at crawling speeds to eliminate dynamic effects.
This paper discusses the details and key findings of the investigation.

We.3.C.4 14:45

Long term monitoring of a UHPFRC-strengthened bridge deck slab using strain gauges

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The Chillon viaducts, located in Geneva Lake region, Switzerland, are two parallel bridge structures with total length of 2.1km and spans varying from 92 to 104 meters. Built between 1966 and 1969 using prestressed post-tensioned prefabricated concrete elements and strengthened with UHPFRC (Ultra High Performance Fibre Reinforced Cementitious composite) in 2014/2015, they carry two motorway lines each. As the viaduct links west and south of the country, high road traffic loads are present and the fatigue behavior is of concern. Thus, the monitoring campaign was commenced in May 2015.
The representative span of one of the viaducts was instrumented with strain gauges and thermocouples. The strain gauges were installed directly on the reinforcement bars in the longitudinal and transversal directions. This paper presents the main outcomes after more than 2 years of monitoring. The considerations on traffic induced stress variation, thermal strain effects and seasonal changes of structural response are presented.
The two years long monitoring has proven that the structural response is much smaller than calculated using load models from standards. Furthermore, the traffic induced strain magnitude is comparable with thermal strain variation, showing outstanding performance of the structure after strengthening with the UHPFRC layer.

We.3.C.5 15:00

Design Optimisation of Cable-Stayed Bridge Based on Cable-Bridge Resonance Control

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Multi-cable systems are usually applied to modern cable-stayed bridges. In such bridges, some steel cables are prone to unfavourable cable-bridge resonance, if the whole bridges vibration frequencies match the natural frequencies of these cables. To avoid this problem, optimisation based on cable-bridge coupled vibration control should be account in the design. In this paper, such optimisation process for a real cable-stayed bridge is presented. A fine finite element model of the cable-stayed bridge was established and the non-linear dynamic analysis was performed. Then the cable material of the stay cables that occur resonance was changed from steel to CFRP. CFRP (short for carbon fibre reinforced polymer) is an advanced composite material, whose strength is higher than steel but density is much lower. The results show that changing the cable material from steel to CFRP and hence increasing the cable natural frequency can effectively prevent the occurrence of cable-bridge resonance. This paper can provide a useful reference to bridge designers.

We.3.C.6 15:15

Reliability assessment of cable-stayed bridge subjected to blast loading

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One of the major issues for a structure is to control the collapse mechanism. In particular, it is important to understand the consequences of actions to the structure. The safety requirement can easily be checked for well-known exerting actions on the structure, but there are, on the other hand, hazards which are often difficult to be predicted and then increase the complexity in the design. The aim of this study is to evaluate the damage induced by an accidental load such as blast loading to a cable-stayed bridge. In the first part of the paper, the non-linear pushover analysis of the structure has been performed to evaluate the limit state of the structure for a random position of blast loading, then through non-linear dynamic analysis, it was possible to collect the stress and strain states of the structure

in the action time history and finally, the frequency of observed damage was presented in term of loading parameters. The major finding shows that the cable-stayed bridge presents a different structural behavior in relation to the position of load. In addition, through the analysis, it is possible to predict the possible damage state during hazards such as blast loading.

We.4.A | DURABILITY AND CORROSION MONITORING OF CONCRETE INFRASTRUCTURES

We.4.A.1 16:30

The new DGZfP Specification B12 „Corrosion Monitoring of Reinforced Concrete Structures“

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The corrosion of steel in reinforced concrete structures is one of the main threats to their durability. Based on the scientific achievements of the past decades the knowledge about the deterioration mechanisms and possible repair strategies for corrosion induced damages have found their way into practice. It is common sense, that a detailed assessment of the structure is the foundation for a successful repair measure. In addition to the traditional singular on-site-procedures such as measurement of concrete cover, carbonation depth, half-cell potentials and chloride contents the monitoring of corrosion related parameters has gained in importance over the past few years.
The advantages of a corrosion monitoring are obvious. In new buildings, structural elements which cannot be assessed after completion (e.g. tunnel segments), or members with electrically isolating coatings can be monitored by means of integrated sensors providing an insight into the development of crucial parameters such as electrochemical potentials, corrosion currents and the electrical resistivity of the concrete. A less known but very beneficial field of application is the use of corrosion monitoring as an integral part of a repair measure based on principles such as the cathodic protection of steel in concrete (CP) or increasing the electrical resistivity of the concrete (IR). By implementing a corrosion monitoring system, it is possible to survey the time dependent effect of the repair measure on the corrosion process which may lead to a confirmation of successful repair measure or to a modification of the repair strategy.
As the principle of cathodic protection for steel in concrete is a recognized repair measure today, the number of applications increases steadily and thus increasing the relevance for corrosion monitoring. Nevertheless, no standards or guidelines concerning the corrosion monitoring are available in Germany today, making it difficult to implement corrosion monitoring in common practice.
With this in mind an international task group formed to develop the specification B12 Corrosion Monitoring of Reinforced and Prestressed Concrete Structures published by the German Society for Non-Destructive Testing, DGZfP, spring 2018.
This paper will present the new specification B12 by highlighting the basic measurement principles and illustrating the potentials of corrosion monitoring for new and existing concrete structures by means of case studies.

We.4.A.2 16:45

General aspects on the assessment of reliability of corrosion monitoring systems

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The average age of our infrastructure is increasing constantly and with the age increases as well the corrosion probability of the reinforcement. Therefore, regular corrosion condition control plays an important role in the through-life management of existing structures. The most common corrosion inspection method is the half-cell potential measurement but continuous corrosion monitoring becomes more and more important. One substantial contribution to strengthen the use of corrosion monitoring is given by the DGZfP-Specification B12 corrosion monitoring of reinforced and pre-stressed concrete structures. The specification presents the fundamental measuring principles and shows practical case studies on the application of corrosion monitoring in newly built and existing structures. Thus, the corrosion condition control enables the decision making for further maintenance and undertaking interventions and consequently, these data must be reliable. However, the evaluation of the reliability of corrosion monitoring systems hasnt received any attention in literature up to now and neither the DGZfP-Specification B12 gives any advice. The evaluation of the reliability of monitoring systems needs to consider some other issues in comparison to inspection methods. Therefore, the objective of this paper is the discussion on the general aspects for the reliability assessment of corrosion monitoring systems in reinforced concrete structures.

We.4.A.3 17:00

Novel sensor for non-destructive durability monitoring in reinforced concrete

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Reinforced concrete is generally a durable material; however, it is also subjected to various degradation mechanisms, amongst them, corrosion of the reinforcing steel is the main one. In addition to loss in safety and serviceability, reinforcement corrosion causes high economical losses in all industrialised countries. Furthermore, costs associated with corrosion of the reinforcing steel are expected to significantly increase in the next years; this is because most of concrete structures have been long exposed to ingress of chlorides (e.g. de-icing salts, seawater) and CO_2, the main aggressive agents that leads to corrosion initiation. There is currently a lack of knowledge and no data is available to determine whether the structure can be in service as this point; this forces engineers to take conservative measures, leading to the early repair of the structure.
Most of concrete structures built in industrialised countries will be reaching a critical age in the next years and will have to operate beyond their service life; based on the current conservative maintenance approaches, this would lead to a strong increase in the number of structures needing repair and the corrosion costs. Thus, there is a high need to quit conservative approaches and find cost-efficiently diagnosis.
In this work, we present a novel sensor to be embedded in concrete and to monitor the main parameters that lead to corrosion initiation,

namely pH and chloride concentration, in combination with the relevant parameters associated with corrosion state and propagation: corrosion potential, electrical resistivity and temperature.
We believe this approach will significantly improve durability monitoring in reinforced concrete; as the data obtained will provide a better insight on the corrosion state of the structure at the different locations over time. Use of this data will allow postponing repair in a safe way and optimize maintenance and planning. First results from pilot projects of embedding the sensor in engineering structures will be shown.

We.4.A.4 17:15

On-site monitoring for studying the effects of repair measures on corroding steel in chloride contaminated concrete

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Among the approximately 5,000 bridges, which are maintained by the road authority ASFiNAG, a total number of 1,500 objects are ramp bridges or overpass structures. Particularly their substructures are subject to increased chloride contamination. Sooner or later, this leads to a reduction in durability and affects the service life in the long term. Therefore, repair measures are necessary. In order to guarantee an optimal structural condition with the available budgets, the costs and effects of repair measures must be known.
This paper is dealing with data collected from an on-site monitoring and also with data from nearby weather stations. For several years, monitoring has been carried out on supports of a bridge exposed to a high chloride load. The sensor measuring principles used to monitor the corrosion behaviour and the sensor design will be explained. First measurement results of this method will be shown, and the seasonal course can be easily traced on the basis of the evaluated data. With this data it is possible to show many interrelations and dependencies to the corrosion rate.
The observations after the repair measures are of particular interest. Now a direct statement can be made about the effectiveness of measures and a performance index can be proposed.
Based on these in-situ measurement results, important statements can be made for future repairs measures.

We.4.A.5 17:30

Corrosion monitoring of cracked concrete structures – state of knowledge and case studies

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Reinforcement corrosion due to chloride ingress is probably the most important deterioration mechanism of our concrete infrastructure. Especially for parking structures, the formation of cracks can lead to an accelerated chloride ingress and as a consequence to corrosion initiation after a comparably short time of use. It has been shown that depending on the exposure conditions even one winter period can already be sufficient to initiate reinforcement corrosion.
The conventional approach for the rehabilitation of chloride-contaminated concrete structures is to remove the concrete adjacent to the affected reinforcement layer, rebuild the concrete cover with chloride-free concrete and apply an adequate coating system in order to avoid chloride ingress during future use. This method is often very expensive and time-consuming and may cause significant inconveniences for users and consumption of resources. Despite these drawbacks, it is still generally considered the standard refurbishment procedure, with cathodic corrosion protection being the only technically sound alternative. However, both recent research activities and field applications suggest that for cracked concrete structures with moderate chloride contamination, the combination of a crack-bridging coating system and a corrosion monitoring system for the monitoring of time-dependent changes of corrosion activity may be an economic and resource-efficient approach.
This contribution will take a closer look at the current state of research regarding the mechanisms that lead to the reduction of corrosion in cracked concrete. Case studies will explain the design and installation of the corrosion monitoring system. Results of the monitoring results after the first months of application will be presented and discussed, thus illustrating the vast potentials of this rehabilitation method.

We.4.A.6 17:45

Flying corrosion inspection robot for corrosion monitoring of civil structures – First results

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Potential mapping permits an early detection of corrosion and has major advantages over a purely visual condition assessment. The current manner of assessing the corrosion state of reinforced concrete structures with potential mapping is limited due to the lack of accessibility, leading to high involvement of manpower and finally to high inspection costs. A main challenge in the coming decades will be the assessment of our ageing infrastructure and their repair. Automating corrosion assessments of structures by an inspection robot will increase the use of non-destructive test methods and the quality of assessments and consequently lead to a more profound basis for the decision making and planning of the maintenance of the ageing infrastructure and lower inspection costs. At ETH Zurich, the development of an omnidirectional flying inspection robot is currently being tackled as a collaborative effort between two research groups. The flying robot will collect the following data from the structure: (1) images of the surface, (2) potential of the steel and (3) electrical resistance between the sensor to the reinforcement. These measurements require the sensor to make physical contact with the concrete surface. As this contact task requires high stability and full 6 degree of freedom force and torque tracking to be robust in the field, no commercially available robot can be used. Preliminary flight tests with the electrochemical sensor mounted on the inspection robot on a laboratory sample demonstrate that potentials and resistances can be successfully measured, with results similar to measurements taken by hand.

We.4.A.7 18:00

Numerical Modelling of Corroded Reinforced Concrete Beams Based on Visual Inspection Data

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Chloride-induced corrosion in existing reinforced concrete structures remains a main issue for structural engineers. It is a challenge to predict the structural effects of the deteriorations caused by corrosion, such as formation of pits in the rebar, cracking of the concrete cover and the loss of bond strength. Recent research on corrosion damage has focused on four aspects; inspection techniques and condition assessment, micro-modelling of the corrosion process, empirical damage relations and macro-modelling of the behavior of corroded beams based on experimental data. Although the models in literature provide good predictions in comparison with experiments, they are mostly based on the real mass loss that is quantified after extracting the bar from the beam. However, the mass loss is a quantity that is not exactly known from on-site inspection.
Therefore, the following paper proposes a novel modelling framework that links visual inspection data to a 2D numerical model of a beam through damage relations. The aim is to study the efficiency of a 2D modelling approach in predicting the behavior of corroded RC beams by using damage relations that are based on visual inspection data. Simulating the inspection-based study is based on the experimental data provided by A. Torres-Acosta et al. (2007). In a first stage, classification of the beams into different corrosion levels is performed according to the damage data provided. In a second stage, reductions are applied to the section, material and bond properties as a function of the reported damage levels and adopted damage functions. Hereafter, the numerical results are validated against the experimental load-deflection curves. Firstly, this approach is followed by using the reported mass and section losses of the rebars. In a second alternative approach, it is assumed that the cross-section loss is not known and therefore it is predicted through the reported crack width measurements, thus simulating an inspection-based modelling strategy. The findings of the paper will report on the accuracy of the inspection-based methodology within a deterministic framework, the efficiency of the adopted damage relations as well as the efficiency of updating a 2D beam model in predicting the structural behavior of corroded beams based on crack width measurements.

We.4.B | DURABILITY ISSUES AS RELATED TO HARSH ENVIRONMENTS – FIRE PROTECTION SYSTEMS

We.4.B.1 16:30

Durability Evaluation of Embedded GFRP Rebars in Concrete Bridges after More Than Ten Years of Service

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Corrosion has been an issue in the civil engineering industry since the day steel was used as a building material. The National Association of Corrosion Engineers estimated a corrosion repairing cost of eight billion dollars per year. Thus, finding an alternative has been a must. One of these alternatives is glass fiber reinforced polymer (GFRP). It presents itself as a solid candidate not only because of its high resistivity to corrosion but also because of its cost efficiency. The goal of this study is to assess the durability performance of GFRP rebars embedded in several bridges across the United States. GFRP rebars were extracted from bridges located in Missouri and Texas States and then were tested for durability at different universities, one of them was Missouri University of Science and Technology. Several tests were conducted on these extracted rebars and the surrounding concrete including: energy dispersive spectroscopy, short bar shear, burn-off, pH, carbonation depth, and chlorides content. Regarding the results, energy dispersive spectroscopy did not show any changes in the GFRPs chemical compositions. Burn-off test did not also show any significant changes in the fiber content. However, short bar shear (SBS) showed some substantial changes for one of the bridges. Carbonation depth test did not show any signs of carbonation attack for the Southview Bridge and was between 13 mm to 25 mm in Sierrita de la Cruz Creek Bridge.

We.4.B.2 16:45

Corrosion Resistance of Calcium Aluminate Cement Concrete Subjected to Sulfuric Acid

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Concrete structures in oil and gas industry are often exposed to the highly corrosive sulfuric acid environment. The natural gas production and processing facilities are prone to attack from acidic vapor at high temperature. The waste molten sulfur produced in the SRUs of the gas plants generates sulfurous and sulfuric acid vapors in a sealed reinforced concrete tank. These acids attacks concrete element triggering severe deterioration of concrete, reducing the service life of the structure and causing a steep rise in the maintenance expenses and enhancing the time for bringing the plant online. Several types of concrete mixes have been investigated extensively for enhancing the service life of concrete structures under acid attack. Calcium aluminate cement investigated under biogenic sulfuric acid attack shows higher performance as compared to ordinary Portland cement. This paper presents the results of investigation conducted on calcium aluminate (CA) concrete subjected to 5% sulfuric acid solution at ambient and high temperatures simulating the environment in molten sulfur tank. The effect of acid on physical and mechanical properties of the CA concrete and microstructural characterization of acid exposed using SEM/EDS and XRD is presented. CA concrete gave a superior performance in terms mass loss and strength degradation.

We.4.B.3 17:00

Experimental investigation on physico-mechanical properties of natural building stones exposed to high temperature

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Fire has always been a major threat to building and consequences can then be dramatic. Since natural stones were frequently used as

building material in historical monuments, a detailed understanding of thermal damage and failure mechanical behavior of these porous materials at elevated temperature is a key concern. When exposed to fire, natural stones can suffer from irreversible changes in microstructure and mechanical properties. These disorders may compromise the structural integrity and increase the risk of instability of the entire building. Thereby, the aim of this study is to understand the effect of fire and identify important changes that can occur when selected building stones are experimentally heated up to 200, 400, 600 and 800 °C. Therefore, seven stones with different mineralogy and various physical characteristics are tested after each exposure. Then, damage evolution is determined through measurement of several physico-mechanical properties such as compressive strength, Young modulus, tensile strength, porosity, P-wave velocity but also with mineralogical (XRD) and microstructure (mercury intrusion porosimetry, SEM) modification. Furthermore, thermal behavior is studied with TGA-TDA analysis, thermal deformation measurement and also through thermal gradient monitoring. The first results indicate that natural stones can be highly affected by high temperature exposure. Several initial characteristics such as mineralogy and microstructure can be considered as the main parameters influencing on thermal sensitivity. Overall, when heated until 400 °C, there is not a significant change in mechanical properties which could bring to thermal instability. However, exposure to higher temperatures (600 and 800 °C) leads to an important decrease in compressive strength, Young modulus and tensile strength. This reduction is related to intense thermal microcracking development inside the sample detected with SEM observations, and caused by differential thermal deformation. Indeed, it is also noticed a sharp decrease in P-wave velocity values and the porous network undergoes an extensive alteration through an increase in porosity and a modification in pore size distribution. Finally, TGA-TDA and XRD analysis show that mineralogical transformation such as calcite decarbonatation starts around 650 °C (recorded temperature during a real case of fire), and leads to a significant loss of mass, resulting in a decrease of mechanical properties : the structural stability is then highly unsettled.

We.4.B.4 17:15

Effect of Harsh Temperature Environment on Strength and Durability of Normal and High Strength Concrete

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Concrete is a material which is likely to expose at high temperature during fire. The mechanical properties such as strength, modulus of elasticity, volume stability etc are severely affected at the time of such exposure. In the present experimental study, the effect of elevated temperatures on split and flexural tensile strengths of normal and high strength concrete have been investigated. Test samples were subjected to temperatures varying from 100 - 800 degree Celsius. The split tensile strength and flexural tensile strength of normal and high strength concrete is determined by testing cylinders of 100 mm x 300 mm size and prisms of 100 mm x 100 mm x 500 mm respectively. The specimens were subjected to a heating-cooling cycle at 100 degree Celsius with a hold period of 3 hours. The specimens were cooled in the furnace before testing it for tensile strengths. Similar type of harsh conditions was provided to the specimens at 100C, 200C, 400C, 600C and 800C and their residual strengths were determined. Specimens were also prepared for determining the tensile strengths at ambient temperature environment. It has been observed that the significant losses occur with the increase in temperature for both normal and high strength concrete. High strength concrete (HSC) experienced lesser amount of loss in comparison to normal strength concrete (NSC). Flexural tensile strength was observed to experience a sharp loss at high temperatures but however, split tensile strength experienced a gradual loss, with the increase in temperature. The test results revealed that the effect of high temperature is more severe on flexural tensile strength as compared to split tensile strength. A regression analysis has been done for modeling a mathematical relation of normalized strength with surrounding temperature in terms of characteristic strength of concrete.

We.4.B.5 17:30

The Axial Loading Capacity of Reinforced Concrete Columns Exposed to High Temperature

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Reinforced concrete structures are traditionally designed to carry service loads and lateral forces caused by seismic events. However, recent incidents such as Grenfell Tower fire in London highlighted the fact that fire and high-temperature should be also taken into account as hazardous phenomena that can significantly affect the safety of the reinforced concrete structures. High-temperature exposure can considerably affect the structural performance and load carrying capacity of reinforced concrete members, and therefore lead to a partial or total collapse. To address this issue, this study aims to investigate the axial load bearing capacity of reinforced concrete columns exposed to high temperature. A custom made high-temperature electric furnace was used to test reinforced concrete columns under simultaneous effects of axial load and high temperature. In addition, thanks to its twin unit design, the furnace allows investigating the effects of both water-cooling and air-cooling on the axial loading capacity of the columns after high temperature exposure. Also, an advanced computer control system was designed using Arduino micro-controller to apply any kind of heating curves to the test specimens. In this study, ISO-834 standard fire curve was used for the experimental tests. The main parameters considered within the study are heating duration, and cooling scenario. Dimensions of the column specimens were chosen as 250 × 250 × 1200 mm. The specimens were subjected to a predefined constant axial load during heating and cooling process. Subsequently, in order to obtain the post-fire residual capacity of the reinforced concrete columns using different heating durations and cooling scenarios, loading was continued up till the failure. The results of this study, can be used to develop more efficient methods to design reinforced concrete columns exposed to high temperature.

We.4.C | DYNAMIC VIBRATION-BASED MONITORING, SEISMIC PERFORMANCE

We.4.C.1 16:30

Dynamic load monitoring of a concrete bridge using a fiber optic Distributed Acoustic Sensing (DAS) system

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In the present study, the impact of dynamic traffic loading in the concrete deck of an existing bridge has been investigated using a Distributed Acoustic Sensing (DAS) system. The dynamic load results in excitation of Eigen Modes of the concrete deck which have been investigated using dynamic strain measurements at various locations simultaneously. The results of the load tests on Amsterdam bridge 705 make an important contribution to the understanding of its structural behavior. The evaluated data can be used to verify and enhance finite element models contributing to the safety assurance of the bridge. In the face of ageing structures, increasing traffic density and severe traffic loading on existing infrastructure, a safety evaluation based on accurate distributed fiber optic measurements can be an important means to estimate remaining lifetime of the bridge. The concept of the dynamic loading was based on the use of a tram passing by and a well-defined movement of a 36-ton truck. The load applied in this way led to location-dependent small deflections recorded as longitudinal strain of the sensing fiber embedded at the underside of the bridge. The laying of the 96-m long sensing fiber in one piece across and along the bridge serves to obtain distributed two-dimensional dynamic strain data. The achieved results demonstrate the capability of the applied system and method to detect dynamic strain signals in the range of a few µm/m at the spatial resolution of 1 to 10 meter along the 96-m long sensing fiber. The measurements were performed with an inhouse developed DAS system based on Rayleigh scattering.

We.4.C.2 16:45

Dynamic Monitoring of Steel and Concrete Offshore Structures

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Steel jacket platform and gravity based structure located and operating in Italian offshore sea are monitored with a continuous dynamic system to investigate the structural response to the sea storms and earthquakes. In order to make a long-term dynamic monitoring, are located on the structures some acceleration units positioned at different elevations, each unit can contains linear or angular accelerometers.
The numerical elaborations are performed through the experience gained over 10 years of continuous dynamic monitoring, and compared the behavior of one steel structure, tubular jacket type with pile foundation, and one gravity reinforced concrete structure.
The paper deals with data collection and the statistical analysis of the structural dynamic response data recorded during the normal work, during the storms and seismic events; the accelerometer data are used to compare design accelerations of the structures, and to determine the natural frequencies and relevant model shapes after the events.
For this purpose, methods of Operational Modal Analysis (OPA) and methods of the principal components (PCA) can be used to highlight structural damage states. The identification methods are applied to two offshore structures that have different frequencies and different dynamic behaviors.

We.4.C.3 17:00

Vibration Analysis of Structures using a Drone (UAV) based Mobile Sensing Platform

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The identification of the dynamic behavior of a structure, like bridges and towers, is relevant to address multiple issues. The frequencies, damping and mode shapes of a structure influence the usability of a structure, e.g. comfort, and they are needed to validate Finite Element Models of a structure, as an important parameter for damage detection systems or for fatigue estimations. In many cases the dynamic parameters should be acquired only once or at a periodicity that doesnt justify the installation of distinct vibration sensors for a long-term monitoring. For structural health monitoring reductions of the eigen frequencies are related to a loss of stiffness in the structure and an ongoing degradation process over several years of the buildings lifetime. To identify modal frequencies of a structure, a drone based mobile sensing platform has been implemented. This sensing platform measures the relative displacement between the structure and the UAV, which also shows a strong dynamic behavior under wind turbulences. The optical measurement system is a long-range triangulation sensor, that has a sufficient sampling rate and accuracy. By combination of a dynamic model of the drone, internal IMU data and additional measurements at the sensor the absolute movement of the structure can be estimated based on the measured relative distance. This time domain data is suitable to be used as input for various operational modal analysis algorithms or simply to apply Fourier transform. In the spectrum the relevant frequencies can be identified. This system has been used to identify the dynamic properties of a test specimen and a real structure, a 1.5 MW wind turbine tower. In the next step a path planning of the flight path will allow to identify dynamic parameters of structures that are located closely together, like in wind parks.

We.4.C.4 17:15

Assessing Seismic Failure Probability of Hospital Emergency Power Supply Systems and Software Development

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First-aid hospitals are facilities that play a critical role in receiving the injured and performing emergency operations during severe earthquake events. Hospitals must not only maintain the safety of their building structures but also ensure the functionality of their nonstructural components and systems, including emergency power supply systems (EPSSs), water supply systems, communication systems, and a range of medical equipment and systems. Since EPSSs provide electric power for other equipment and systems, it is reasonably considered the most important. Therefore, in this study, we

focused on the failure probability analysis of EPSSs and took one hospital in the Great Taipei metropolitan area as our research target. Fragility data of its EPSS components were firstly analyzed by using the fragility function proposed in a previous study. Then, a system logic tree observing the relationship among components would be plotted, enabling failure probability estimation of the whole system in response to varying peak ground acceleration (PGA) values at the site. In order to efficiently identify the seismic risk for medical facilities, this study applied the assessment model and further developed a seismic risk assessment system of first-aid hospitals, or T-Hospital. In T-Hospital, the Rapid Earthquake Information Release System is integrated for real-time earthquake event information, and all first-aid hospitals are classified to three levels: low, moderate, and high. At present, the seismic risk of EPSSs in hospitals could be shown on T-Hospital immediately after an earthquake event.

We.4.C.5 17:30

Estimating seismic interstory drifts of building structures using time-varying shear model with acceleration data

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Structural health monitoring (SHM) of important building structures, used as disaster-response bases, financial centers, hospitals and so on, in earthquake-prone areas are essential because it can facilitate rapid decision making on evacuation and re-occupancy after a great earthquake. Interstory drift is an important engineering demand parameter and key indicator of structural performance owing to its correlation best with seismic damage of building structures. This paper presents a time-varying shear model-based method for estimating seismic drift responses of building structures using acceleration measurements at a limited number of stories. A drift estimation algorithm is first formulated on the basis of state estimation of a time-varying shear building model using the unscented Kalman filter. The parameters of stiffness and damping are time-variant considering the fact that structural stiffness and damping vary during earthquakes. Then, the effectiveness of the presented method is numerically investigated through a four-story hysteretic shear building model subject to an earthquake motion recorded in the 1989 Loma Prieta earthquake.

We.4.C.6 17:45

Reconstruction Cost and Insurance Refunding Empirical Evidences for Long-span-beam Buildings Struck by the 2012 Emilia-Romagna Earthquake

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From the 2012 Emilia-Romagna earthquake much can be learnt in terms of seismic economic consequences. The public institutions need for comparable and accessible data, to be used within the reconstruction process, is the reason why researchers can finally put their hands on a vast, consistent and reliable seismic damage and loss database. In particular, after the 2012 seismic sequence, the local administrative authority, Regione Emilia-Romagna, started collecting relevant information regarding consequences occurred to structures and infrastructures, public housing, cultural heritage and business facilities. For what concerns the latter, the so-called SFINGE database was assembled in more than 6 years of reconstruction process. In SFINGE, among other things, reconstruction costs and insurance refunding were documented. In this paper, the author presents some results obtained by exploring such database, processing and checking data on thousands of buildings. In particular, long-span-beam structures were taken into consideration: for them, empirical evidences are plotted and summarized. Study results can be included within the state of the art of seismic performance assessment tools.

We.4.C.7 18:00

Seismic Performance of Reinforced Concrete Girders of an Existing Building Constructed in 1971

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In Japan, seismic performance of existing buildings has typically been evaluated by the standard based on their structural drafts. In many existing buildings however, differences between actual members and the structural drafts have been found. Therefore, it is very difficult to evaluate the accurate seismic performance of an existing building. Experiments were performed on two reinforced concrete (RC) girders taken from a two story residential building constructed in 1971. The average concrete strengths of each story were 17.3 and 9.54N/mm2, respectively. The girders were designed to have shear spans of 1200 and 1000mm, respectively, so that the validity of the current equations for determining the shear capacity for seismic assessment could be evaluated. The ratios of the calculated shear strength to the calculated flexural strength of the girders were 1.21 and 1.02, respectively. The girders were initially subjected to reversed loading, with displacement control up to 1% drift angle. After initial loading, the damaged girders were repaired via epoxy resin injection to investigate the effect of retrofitting assuming that the RC members were severely damaged due to an earthquake. Then, the retrofitted girders were reloaded until failure occurred.
In initial loading, the maximum stregnth of the original girders reached the estimated flexural strength, although shear clacks were observed. The maximum strength of the retrofitted girders reached 1.18 and 1.13 times those of the original girders.
We found that epoxy resin injection improved the seismic performance of the RC members of existing buildings.

We.4.D | PRACTICAL APPLICATIONS AND CASE STUDIES (I)

We.4.D.1 16:30

Mobile LIBS-System for condition assesment of concrete structures on-site

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In view of the ageing of vital infrastructure facilities a reliable condition assessment of concrete structures is becoming of increasing interest for asset owners to plan timely and appropriate maintenance

and repair interventions. For concrete structures reinforcement corrosion induced by penetrating chlorides is the dominant deterioration mechanism affecting the serviceability and eventually structural performance. The determination of the quantitative chloride ingress is required not only to provide valuable information on the present condition of a structure, but the data obtained can also be used for prediction of its future development and associated risks.
At present wet chemical analysis of ground concrete samples by a laboratory is the most common test procedure for determination of the chloride content. As the chloride content is expressed by mass of binder, the analysis should involve determination of both the amount of binder and amount of chloride contained in a concrete sample. This procedure is laborious, time consuming and costly. The chloride profile obtained is based on depth intervals of 10 mm. In most situations increments of 10 mm are less appropriate for quantification of input parameters used in modelling.
LIBS is an economical viable alternative providing chloride contents at depth intervals of 1 mm or less. It provides two dimensional maps of quantitative element distributions and can locate spots of higher concentrations like in a crack. The results are correlated directly to the mass of binder and it can be applied on-site to deliver instantaneous results for the evaluation of the structure.
The application of a mobile LIBS system in a parking garage is demonstrated. It uses a diode-pumped low energy laser (3 mJ, 1.5 ns, 100 Hz) and a compact NIR spectrometer. A scanner allows a two-dimensional element mapping. For the quantitative analysis calibration of the system is carried out with reference samples in a concentration range of chlorine of 0.05 to 2.5 wt.%. Results show the quantitative chloride analysis on wall and floor surfaces. To determine the 2-D distribution of harmful elements (Cl, C), concrete cores were drilled, split and analyzed directly on-site. Results obtained were compared and verified with laboratory measurements.

We.4.D.2 16:45

Long-Term-Monitoring of CFRP-cables over almost a quarter of a century

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Number and weight of vehicles in traffic are continuously increasing, resulting in a growing burden for the in-frastructure, especially for older bridges. But it is economically desirable to extend the safe use of them as long as possible. Implementing structural health monitoring (SHM) aims to detect critical deviations in due time. In particular, long term monitoring can help to verify the stability of critical parameters.
For the measurements described in this contribution the use of carbon fiber reinforced polymers (CFRP) for tensioning cables and their long-term behavior is of interest especially their anchorage system is important.
We had the opportunity to implement our measuring systems on three different bridges: a stay cable bridge, a steel-concrete composite bridge and a retrofitted reinforced concrete bridge. The earliest measurements were performed in April 1996, so we have performance records for a time period of over 23 years not only for the sensors but also for the whole measuring chain.
Compared with the long infrastructure lifecycle of many decades, a sensor lifetime is usually much shorter and components or sensor systems have eventually to be replaced over the monitoring period. Essential is a reli-able and long-term stable measuring system. Reference measurements not only in the laboratory but also on the infrastructure have been carried out over the same period. The collected data are essential to discriminate between change of the infrastructure object and sensing artefacts.
This contribution gives an overview of the long-term data obtained in-situ and in the laboratory covering a time period of almost a quarter of a century. The applied sensors are based on resistive strain gages, fiber Bragg grating sensors and inductive displacement transducers. The reference data allows quantifying the measurement uncertainty, stability and reliability of long-term measurements including the fact that some sen-sor failed or are suboptimal and are influenced by the environment.

We.4.D.3 17:00

Structural Health Monitoring of Bridges in Mexico – Case Studies

J.R. Gaxiola-Camacho [1], J.A. Quintana-Rodríguez [2], G.E. Vazquez-Becerra [1], F.J. Carrion-Viramontes [2], J.R. Vazquez-Ontiveros [1], F.J. Lopez-Varelas [1]
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Although bridge engineers around the world design structures following codes, recommendations and/or guidelines to ensure safety for the entire life of the bridges, several of them have collapsed or presented considerable damages, mainly for disregarding important issues during the design or construction processes. Thus, once bridges are constructed, it is difficult to identify these structural discrepancies before they become critical. As an alternative, the Structural Health Monitoring (SHM) of bridges has been implemented worldwide. The main objective of the SHM of bridges is to extract as accurate as possible the real performance of the existing structures to evaluate structural behavior, detect and evaluate damage and structural prognosis. It is documented that the SHM paradigm of bridges emerged by the end of the 80s. Since then, the state of the art and practice have positively increased, improving several parts of the SHM as data acquisition, normalization and cleansing. For instance, to extract the structural behavior of structures, accuracy and efficiency have been improved in electronic devices as strain gauges, LVDTs, inclinometers, and GPS receivers. The principal contributions to the state of the art and practice of SHM of bridges have been reported in countries as Canada, United States, United Kingdom, Switzerland, Portugal, and Australia. However, the authors of this paper believe that some outstanding contributions in SHM have been developed in Mexico as well. Three case studies of SHM of bridges in Mexico are documented in this paper. Firstly, the SHM of the Papaloapan Bridge, that was designed and installed for the structural assessment of this cable-stayed structure after several deficiencies in the upper anchoring elements that caused two failures and loosening of cables. Secondly, the structural assessment of the El Carrizo Bridge, which has a box girder cantilever structure section that was damaged after a fire provoked by an accident of a vehicle transporting Diesel. In this case, the SHM system was installed to control the overall rehabilitation and to guarantee its structural integrity. Finally, the case of the probabilistic SHM strategy for a reinforced concrete bridge, where the probability of failure is calculated evaluating displacements obtained via GPS technology. Based on the results and, although the diversity of cases, SHM has demonstrated to be a useful and a cost-effective tool, not only for evaluating critical con-

ditions and rehabilitation, but also for future structural integrity and prognosis of bridges.

We.4.D.4 17:15

Damage Assessment of Concrete Sulfur Storage Structure in Petrochemical Industry

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In petrochemical industry, gas sweetening process results in the formation of acid gas consisting of H2S, CO2 and water vapor, which is sent to the Sulfur Recovery Units to recover sulfur. Molten sulfur maintained in a liquid phase at temperatures ranging from 130 °C to 160 °C are stored in reinforced concrete sulfur pits, constructed below grade to facilitate gravity flow. The reinforced concrete structural elements in sulfur pits are exposed to acidic gases and sulfuric acid vapor fumes at high temperature resulting in delamination, spalling, cracking and reinforcement corrosion instituting threat to structural integrity. This paper presents the field and laboratory investigations conducted on a 30-year-old, in service sulfur pit. NDT based investigations of the top slab of the pit was carried out using the ground penetrating radar, ultrasonic pulse echo, and half-cell potential measurements. Effect of high temperature molten sulfur exposure on concrete in sulfur pit is examined using petrographic examination, SEM/EDS and XRD tests.

We.4.D.5 17:30

Fracture characteristics of cold jointed concrete identified by acoustic emission technique

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Sequence and quality of concreting is important factors effecting strength of the concrete members. Because to cast whole structure monolithically is very difficult, delayed concreting causes cold joints which are the weak transition zones between two different concrete layers. These regions have serious consequences particularly at columns, beams and column-beam joints. A large number of studies can be found in the literature mentioning about detrimental effects of cold joint and prevention of it. However, identifying fracture mechanism of this zone is still an unstudied issue. In this study, to reveal fracture characteristics of cold jointed concrete was aimed. For this purpose, acoustic emission (AE) monitoring, which is a developed nondestructive testing method, was performed experimentally. A reference monolithic and cold jointed concrete beam specimens were produced in the laboratory and were tested under bending. Besides mechanical features, invisible fracture characteristics were also identified and influences of cold joint were determined.

We.4.D.6 17:45

Satellite-based InSAR Monitoring – Validation on Victoria Bridge in Montreal, Canada

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Public transportation agencies need reliable monitoring technologies to provide advance warnings of pending failure of their valuable assets, probability of which may increase due to climate change. To address this concern, a partnership was formed to validate a satellite-based bridge monitoring approach by comparing its results to analytical predictions. A previous validation study on a new bridge made of concrete deck on steel box girders found a good match between satellite-measured thermal displacements and those from numerical predictions calibrated on sensor measurements. With the aim of validating the approach on different structural systems, this paper presents the findings of a 2nd validation study on a historical bridge made of steel grating deck supported by a steel truss structure. Two sets of satellite imagery with different viewing angles were used to allow decomposition of measurements into vertical and longitudinal components of displacement for direct comparison with predictions. Results confirmed the validity of the approach and indicated which bridge features can be best monitored accurately.

Th.1.A | KEYNOTE PRESENTATIONS

Th.1.A.1 08:30

Extending the Strengthening Potentialties of Near Surface Mounted Technique: From Experimental Evidence to Advanced Numerical Simulations

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Research activities have demonstrated that near surface mounted (NSM) technique is very efficient for the flexural, shear and torsional strengthening of reinforced concrete (RC) elements. When combining NSM with partially of fully confinement FRP-based configurations, highly effective strengthening solutions are obtained for enhancing the seismic performance of RC columns. Innovative confinement FRP-based configurations, applied with a certain prestress level, have been explored for increasing the strengthening effectiveness in case of RC columns of rectangular cross section. The flexural strengthening performance of RC beams and slabs can be significantly increased by applying NSM FRP reinforcements with a certain prestress level, mainly for serviceability limit state conditions, with complementary benefits on the durability of these structural elements due to crack closing favorable effects.
New geometries for the NSM FRP reinforcements have been also proposed, by disposing their extremities with a certain inclination in order to have both flexural and shear strengthening functionalities, as well as better anchorage conditions. These new type of FRP reinforcements have been demonstrated capable of assuring simultaneous flexural and shear strengthening capabilities for RC beams, simultaneous flexural and punching strengthening capabilities for RC slabs, and very efficient for the flexural strengthening of cantilever type RC elements like balconies. Since the extremity parts of these new types of FRP reinforcements are applied according to the embedded through section (ETS) technique, they are better protected against the detrimental effect of a fire, providing to these reinforcements a tendon-like working in case of a fire occurrence, with the consequent favorable effects. These aspects combined with the recent developments of high performance cement based adhesives

bring new opportunities on the use of these materials and strengthening techniques, even in extreme loading scenarios.
The knowledge derived from the experimental research activities is being enriched by those obtained from the analytical formulations and advanced numerical simulations, towards the development of comprehensive and reliable design approaches.
This keynote lecturer aims to make an overview of these relevant aspects for contributing to a broad understanding of the potentialities of the NSM technique and how they can be extended and used for constituting technical and cost competitive strengthening solutions for the built environment.

Th.1.A.2 09:10

Recent Advances on Assessment of Seismic Performance of Existing Structures

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Seismic performance assessment is used to determine the likely resistance of an existing building to a considered earthquake effect. For this reason, several levels of performance assessment procedures can be employed depending on the need and building population. Detailed performance assessment procedures require thorough investigation of the building to obtain information about the as-built properties and to construct the structural plans that are needed for the analysis of the building. Earlier procedures given in FEMA 273 and ATC-40 were outlined in the form of guidelines. In the following years, as performance assessment gained more popularity, revised procedures were incorporated in FEMA 356 and ASCE 41. In the meantime, some codes have adopted detailed seismic performance assessment procedures for assessment and rehabilitation of existing buildings (Eurocode 8, TEC 2007). Although, the general concept and approach in these code procedures were similar, changes were inevitable due to reflection of local practice and experience especially in acceptance criteria. In this study, advances in seismic performance assessment of existing RC structures are summarized with emphasis on differences among code procedures and changes over time. Research results on comparisons of different existing code performance assessment procedures are presented focusing on the efficiency of each procedure both in terms of assessment results and performance limits.

Th.2.A | TESTING, INSPECTION, MONITORING AND REPAIR OF OFFSHORE WIND ENERGY CONVERTERS

Th.2.A.1 10:20

Comparison of cracks formed in scaled grouted connection of offshore energy structures under static and cyclic loads

G. Hüsken[1], *M. Shamsuddoha*[1], *M. Thiele*[1], *M. Baeßler*[1], *H.-C. Kühne*[1]
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Global energy consumption will increase in the future necessitating both fossil fuels and renewable energy choices especially wind energy. Such high energy demand requires installation of offshore energy structures, rigs, platforms and towers, which are susceptible to adverse environmental conditions along with maintenances. Due to their large size and remote locations, cylindrical grouted joints are often adopted between substructure and foundation in these offshore platforms and wind structures especially monopiles. However, these connections are composite structures with exterior sleeve, interior pile and infill mortar. Degradations and settlements were reported inside similar connections, which were installed in last three decades. Besides, grouting in the offshore sites were proven difficult to obtain ideal capacity. In-situ loading conditions were also found to be affecting the failure mechanism inside such connections. This study aims at characterizing the nature of cracks generated in grouted connections under both static and cyclic loadings. Scaled grouted joints were manufactured using a novel mold, and connections were loaded to failure to visualize the main failure patterns. An assessment between failures under these two types of load is drawn along with comparison to previous available literature.

Th.2.A.2 10:35

Restoration of structural integrity – a comparison of various repair concepts for wind turbine rotor blade shells

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Wind turbine rotor blade shells are manufactured as sandwich structures with fiber-reinforced polymer (FRP) due to the materials high specific stiffness and strength. With a growing renewable energy industry and thereby a spread of wind energy farms, especially in offshore applications, the need to fully utilize turbines through their designed lifespan is becoming increasingly essential. However, due to imperfections during manufacturing, which are then propagated by harsh environmental conditions and a variety of loads, blades often fail before their projected lifespan. Thus, the need for localized repair patch methods for the outer shell portions of the blades has become of greater interest in recent years, as it is crucial to the optimal compromise between continuation of wind energy production, cost efficiency, and restoration of structural performance. To increase the understanding of the effect on the fatigue life of the rotor blades, this study tests localized repair patch methods and compares them to each other as well as to reference, non-repaired specimens. Manufactured with the vacuum-assisted resin infusion process, the shell test specimens are produced as a curved structure with glass FRP sandwiching a polyvinyl chloride foam core to best represent a portion of a rotor blade shell. Patch repairs are then introduced with varying layup techniques, and material properties are examined with cyclic fatigue tests. The intermediate scale test specimens allow for the observation of material as well as structural variables, namely of interest being the stiffness and strength restoration due to the repair patches. Damage onset, crack development, and eventual failure are monitored with in-situ non-destructive testing methods to develop a robust understanding of the effects of repair concepts.

Th.2.A.3 10:50

Comparison of fatigue crack detection methods for high-cyclic loaded steel structures

M. Thiele[1], *R. Makris*[1], *F. Hille*[1]
[1] *BAM, Berlin, Germany*

For the generation of renewable energy offshore wind farms play an important role today. The available free space combined with more

efficient wind conditions make these locations very attractive for generating wind energy. In Europe a number of offshore wind farms are already erected, for example in the North and Baltic Sea. In the future there will be further offshore wind farms build. The majority of these wind generators are mounted on steel foundation structures. Caused by the high-cyclic loading of these structures by wind and waves fatigue plays an very important role.
Besides the consideration of fatigue within the design process it is additionally an important topic and challenge to monitor the existing steel structures relating to potential fatigue cracks occurring during their life time. Since the structures of the offshore wind generators are very large and in addition partially under water effective and reliable methods for fatigue crack detection are required.
This contribution will present some results of investigations on different crack detection methods applied on high-cycle fatigue tests on small welded steel samples as well as on welded steel components. These tests were performed at the laboratories of BAM. As detection method mainly three different methods were used and compared. The first method is the measurement of strains by conventionally strain gauges. Secondly the optical method of crack luminescence was used as a new and effective method for surface observations. And finally the detection by differential pressure of inner and outer areas of tubular steel elements was tested. The comparison of these measurements will show what are the advantages and disadvantages of the different methods and which method is potentially more suitable for the application on real offshore wind structures.

Th.2.A.4 11:05

Effect of repair models on risk-based optimal inspection strategies for support structures of offshore wind turbines

R. Schneider[1]
[1] *BAM, Berlin, Germany*

Owners or operators of offshore wind farms perform inspections to collect information on the condition of the wind turbine support structures and perform repairs if required. These activities are costly and should be optimized. Risk-based methods can be applied to identify inspection and repair strategies that ensure an optimal balance between the expected total service life cost of inspection and repair, and the achieved risk reduction. Such an optimization requires explicit modeling of repairs. In this paper, the impact of different repair models on the results of a risk-based optimization of inspection and repair strategies is quantified in a numerical example considering a jacket-type steel frame subject to high-cycle fatigue. The example showed that, in this specific application, there is no need for detailed modeling of the behavior of repaired welded connections.

Th.2.A.5 11:20

Investigation of the salinization of metal surfaces in marine and offshore environment – test methods and challenges

M. Babutzka[1], *A. Burkert*[1]
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Salinization and contamination of metal surfaces by chloride-containing aerosols is of great importance with regard to corrosion phenomena in the maritime sector and in offshore applications. Especially Offshore Wind Turbines are exposed to extreme corrosive conditions due to high chloride concentrations in the atmosphere and the resulting high chloride deposition rates. It is of great importance to evaluate to what extent salinization of the surface influences the corrosion protection of coatings and pitting occurrence on stainless steels under atmospheric conditions to evaluate the durability of metallic building structures in offshore and marine environments. The evaluation of the scientific literature and regulatory guidelines has shown that there are still many open questions regarding the contamination of metal surfaces by chlorides. This contribution will discuss how salinization of metal surfaces is evaluated and monitored according to current standards and guidelines. Future challenges concerning test methods and the application of evaluated salinization values and deposition rates will be discussed.

Th.2.B | LABORATORY TEST OF THE EFFECTIVITY OF EXTERNAL NON FRP STRENGTHENING LAYERS

Th.2.B.1 10:20

Tensile behaviour and durability assessment of Flax Textile Reinforced Mortar composite systems

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The use of Textile Reinforced Mortar (TRM) composite systems is getting more and more common for enhancing shear and bending capacity masonry walls. In this context, employing natural fabrics deriving from vegetal fibres is a possible evolution in TRM technology, intended at enhancing the sustainability of the material. However, the organic nature of the aforementioned fibres raises new questions about the durability of the material. Therefore, this paper investigates the tensile behaviour of Flax-TRM coupons also considering the effect of their being exposed to different environmental condition. Specifically, according to the acceptance criteria AC434 the specimens have been immersed either in water or salt water or alkali solution for a period of 3000h. The composite material components (namely, the mortar matrix and the flax fabric) have been subjected to the same treatments to quantify their influence in the global response. A series of specimens has been left in ambient condition to get a reference behaviour. The obtained results show that neither the composite system as a whole, nor its components have shown any significant decay in terms of mechanical behaviour with respect to the reference series. The results demonstrate that the investigated Flax-TRM system, exposed to the conventional protocols provided by AC434, complies with the acceptance criteria generally considered for qualifying composite materials.

Th.2.B.2 10:35

Shear strengthening of masonry walls with Flax Textile Reinforced Mortar composite systems

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Masonry constructions built in the past decades in earthquake-prone areas are generally characterised by significant levels of seismic vulnerability. Therefore, strengthening and retrofitting of those

constructions is more and more perceived as a major societal challenge, also in the light of damages and casualties induced by recent seismic events, such as those occurred in central Italy. Several techniques are nowadays available for enhancing seismic safety of existing masonry structures. Among them, the use of composite materials is widely accepted as one of the most convenient options. Besides the first generation of composites materials, based on polymeric matrix, a new type of materials adopting an inorganic matrix is attracting a growing interest within the scientific and technical community: these materials are often referred to as Textile Reinforced Mortars (TRM).
This paper reports the results of a series of tests carried out with the aim to investigate the potential of a novel type of TRM in enhancing the in-plane shear capacity of masonry walls. Specifically, the TRM system under consideration is based on adopting a flax fabric as internal reinforcement. Therefore, it is characterised by high sustainability properties and a mechanical behaviour that has been investigated within a companion paper. The experimental activity confirms the potential in the use of plants fibres based composite systems as reinforcement of masonry elements. In comparison with unreinforced walls tested as reference, the peak load doubled. Moreover, the use of Flax-TRM led to a ductile behaviour never shown in unreinforced walls typically characterised by a brittle response. The research study paves the way for further investigation aimed at both identifying the performance under different load configuration and improving the composite material response.

Th.2.B.3 10:50

Experimental study on the effect of the Prestressed Concrete Cylinder Pipe strengthened by external prestressed strengthening strands

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Prestressed concrete cylinder pipe (PCCP) suffers from cracks and delamination of mortar coating, corrosion and fracture of prestressing wires, longitudinal cracks in the concrete core and leakage of cylinders due to various factors such as external corrosive environment and hydrogen embrittlement. The reinforcement with external prestressed strands is able to actively compensate for the prestress loss caused by broken prestressing wires at an economic price, close the cracks and fully exert the characteristics of the prestressed steel strand, namely, a high tensile strength and its ability to not decrease with an increase in the bending angle. It is also unnecessary to dewater the pipes during construction. To evaluate the reinforcement effect of PCCP with external prestressed strands, a prototype test of PCCP was performed. The maximum width of the cracks in the outer concrete core at spring-line reduced from 1.2 mm to 0.1 mm after strengthening. The strains of the core concrete changed slightly and the width of cracks in the outer concrete core was maintained at 0.1mm when the internal water pressure gradually increased to the design pressure of 0.9 MPa. The strengthened pipe was capable of sustaining the design internal water pressure and the water tightness property was in a good state. The strains of the steel strands were all below the tensile strain level. The reinforcement of PCCP with external prestressed steel strands is able to meet the strengthen requirement of the test and the strengthening effect is evident.

Th.2.B.4 11:05

Effect of carbon textile treatment and embedded textile length on textile/matrix interface behaviour from pull-out test

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The carbon textile-reinforced refractory concrete (carbon TRC) is an alternative material to strengthen or reinforce the structure in some special environments thanks to its advantages. An important factor influences on mechanical behavior of carbon TRC is the bond strength of textile/cementitious matrix interface. In order to improve this bond, carbon textile is treated with different products in manufacturing procedure. This paper presents the results of pull-out tests performed on textile/ matrix interface specimens that were made with two carbon textiles (commercial products with two different fibre treatments), embedded in concrete matrix with different lengths. As results, all interface specimens gave a typical behaviour as shown in the literature with three phases: perfect bonding phase, debonding phase and pure friction phase. In comparison with the results obtained from pull-out tests on the specimens of the same carbon textile embedded in concrete matrix with different lengths, it could be found that the maximal force improved about 1.5 times when the embedded length extended 2 times from 2cm to 4cm. However, its necessary an energy bigger than 4.76 times in order to damage the textile/matrix interface bond in this case. In the other hand, the effect of carbon textile treatment could be found and analyzed. As results, the textile treatment with amorphous silica helped the interface to extend the pure friction phase of its behaviour, while the interface specimens of carbon textile treated with epoxy resin gave a quick failure in third phase after being reached the maximal force.

Th.2.B.5 11:20

Experimental Investigation on the Bond Behavior of Steel Fiber Reinforced Mortar (SFRM) applied onto Masonry Substrates

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Due to its low tensile strength and brittle behavior, the use of concrete as structural material has required the use of tensile reinforcement, traditionally on the form of reinforcing bars placed on the locations in which high tensile stresses are expected. In previous decades, the use of steel, glass, or plastic fibers dispersed randomly on the fresh concrete mix for the total or partial replacement of reinforcing bars has shown to provide significant increase on the tensile and flexural strength, abrasion resistance, permeability, toughness and durability of concrete. The use of this composite material, known as fiber reinforced concrete (FRC) or mortar (FRM), for industrial pavement, tunnel linings, and hydraulic and precast structures has shown satisfactory results. More recently, the use of FRC and FRM for the strengthening of existing concrete and masonry structures has caught the attention of researchers worldwide. Unfortunately, experimental evidence on the topic is still scarce and a significant research effort is required to gain knowledge about the behavior of structures strengthened using these materials. Based on this need, in this paper the bond behavior of steel fiber reinforced mortar (SFRM) applied onto masonry supports is investigated by

means of double-lap shear tests. Results of the tests are discussed in terms of load response, and failure mode.

Th.2.B.6 11:35

Strengthening of Reinforced Concrete Beams with Fabric Reinforced Geopolymer Composite

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Proper strengthening and rehabilitation are essential to extend the lifespan of existing reinforced concrete (RC) structures. Fabric reinforced geopolymer composite (FRGC) is developed and adopted for strengthening of RC beams. The geopolymer matrix is prepared by using industrial by-products (e.g. slag and fly ash) and alkali activators (e.g. NaOH and Na2SiO3). Carbon fabrics are subsequently embedded in matrix to form the strengthening system. Flexural tests of RC beams with and without FRGC are conducted with a focus on the bonding behaviour between FRGC and concrete substrate. Test results indicate that externally bonding FRGC is able to enhance the cracking load, ultimate load and stiffness of RC beams. For instance, the cracking and ultimate loads are increased by 129.3% and 23.8% for the FRGC-strengthened beam, respectively. Installation of shear bolts and U-jacket are effective in preventing premature debonding of FRGC. U-jacket wrapping is recommended as it avoids introducing damage to beams.

Th.2.C | SHM – STRUCTURAL HEALTH MONITORING ON BRIDGES, ADVANCED INSPECTION AND TESTING

Th.2.C.1 10:20

Structural Health Monitoring of a post-tensioned concrete bridge using wireless sensor system: deployment and evaluation

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The fast-developing Structural Health Monitoring (SHM) field includes diverse technologies to assess the status of structural systems and predict their future performance using the data recorded by sensory systems. Wireless sensor network is one of the most efficient sensor technology for monitoring of civil infrastructures by replacing time consuming and expensive conventional wired sensors. In this study, a new developed wireless sensory system is used to extract the dynamic characteristics of a large-scale post-tensioned concrete bridge in Auckland, New Zealand. The sensory system installed on the bridge includes 20 wireless microelectromechanical system (MEMS) accelerometers and one base station unit. The sensor nodes use wireless mesh network with XBee Radio Frequency (RF) module to transfer the measurements including ambient temperature, humidity and 3-axis accelerations from the sensors to the data logger. The advantages of the sensory system are its low power consumption, low cost and high accuracy and resolution for measuring low-amplitude ambient vibration. Also, each sensor in the network has the capability to record both traffic-induced and earthquake-induced vibrations from structures using two time-triggered and event-triggered sampling modes. The dynamic characteristics of the bridge are obtained using the vibration measurements periodically recorded from the structure at a customized sampling frequency. Then, the results are compared to the identified counterparts measured before using standalone MEMS accelerometers to present any possible alteration in the bridge condition over the time. In addition, the performance of the wireless sensory system in terms of hardware permanence, wireless communication, power consumption and software stability is investigated for a robust structural health monitoring system. The dynamic characteristics of the bridge obtained from the ambient vibrations recorded over different construction phases of the bridge show a constant performance of the full-scale structure. Also, the results indicate a reliable performance of the wireless sensor network for SHM of large-scale civil structures.

Th.2.C.2 10:35

A double-pass method for bridge assessment considering surface roughness using normalized contact point responses

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This paper proposes a method to identify bridge modal parameters and detect possible damage location(s) using an instrumented vehicle based on vehicle-bridge interaction considering surface roughness. Existing vehicle-response-based bridge damage detection methods usually ignore surface roughness as it will contaminate the vehicle response data. The double-pass method is built upon the equations of motion of the bridge and vehicle. Then the normalized contact point response is obtained from the reponses of the vehicle passing on the bridge twice with extra mass added during the second pass. The normalized contact point response is relatively immune to the additional excitations due to surface roughness. The frequencies and mode shapes of the bridge can be further extracted from the normalized contact point acceleration with spectral analysis and Hilbert transform. The damage can be located accordingly using wavelet transform and coordinate modal assurance criterion. The effectiveness of the proposed method is verified by numerical simulation. The result shows that the proposed method can extract bridge frequencies and mode shapes, and identify single and multiple damage scenarios accurately in the presence of surface roughness of different classes.

Th.2.C.3 10:50

Remote microtremor monitoring of railway bridge pier for scour detection

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This study is intended to discuss remote microtremor monitoring of railway bridge pier in terms of scour monitoring. The vibration based structural health monitoring (SHM) has been applied to damage detection of structures including highway bridges, but little practical application has been reported. However, in the context of the anomaly detection, vibration-based SHM might be a promising technique for the scour monitoring of railway bridges, as it is well known that changes in the vibration characteristics of the railway bridge pier under scouring is obvious. In fact, the impact test on the railway bridge pier to identify changes in frequencies has been adopted as

a promising scour detection method in Japan. However, the impact test is a laborious and time-consuming method, and is inapplicable for the real time monitoring to make a proper decision on the train operation control during heavy rains. This study investigates feasibility of vibration-based scour monitoring as an alternative method for the impact test. A railway bridge with high potential of scour was monitored utilizing a smart sensing unit which includes functions of vibration measurement, data processing and remote control. The target frequency was slightly decreased under high water level. However, the decreased frequency recovered once the water level decreased. It demonstrated lower chance for occurring scour as the vibration characteristics of the monitoring pier keep constant. It also encourages the use of the proposed sensing unit and microtremor measurement for scour monitoring.

Th.2.C.4 11:05

Effect of Ambient Temperature on Behavior of a Steel Arch Bridge Based on SHM Data

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Structural health monitoring (SHM) is going to be a standard tool for bridge management as a decision support for maintenance. Different strategies have been proposed in literature, using different devices and data analysis tools. This case study deals with a steel arch bridge in the island of Xiamen, China. The monitoring system involves integrated data analysis from different sources, such as vibrations from accelerometers, strain from linear strain gauge (located on the rigid suspenders, on the vault and on the cross-section of the arch rib of the bridges), and finally environmental conditions considering temperature and humidity. Preliminary results obtained using data stored in a long period under different climate and load conditions are presented. Using regressive analysis, the experiential regressive equation of temperature effect and dynamic strain could be decided, and then temperature effect could be separated. Based on the collected data, the effect of ambient temperature on stress, frequency and acceleration of the bridge are analyzed, which provide references for the design of structural health monitoring system. It is further analyzed how the results should be used for a reliable bridge management.

Th.2.C.5 11:20

Remote Monitoring System for Road Condition Assessment and Its Application

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Road networks are one of the most important key infrastructures that contribute to rapid economic growth. At the same time, there is an increasing demand for reasonable preventive maintenance including repairs to the road pavement and other facilities within the road networks, while the roads remain in service, despite limited budgets and human resources. Regarding the road pavement, for example, the maintenance control index (MCI) is used in Japan as an index for judging asphalt pavement damage. The MCI parameterizes the cracking ratio, roughness and rutting depth, but it can also be used as an index based on two attributes or even just one attribute. The MCI inspection of the road pavement is undertaken using a specially designed vehicle. Another useful index is the international roughness index (IRI) proposed as an indicator by the World Bank, which mainly focuses on ride quality and the roughness of road surface including but not limited to asphalt pavements. The IRI is an index defined by applying an algorithm to a measurement of the longitudinal profile. For the indices mentioned above, the soundness of the road pavement is usually evaluated by using an inspection vehicle. Such a vehicle is capable of accurate quantitative evaluation, but its initial and operating costs are usually relatively high, while such vehicles tend to be used infrequently. Other constraints include the road width, radius of curvature, and slope, which cannot be measured with the road inspection vehicle. In addition, there are many features of a road that must be regularly checked, such as road appurtenances, and filled/cut slopes. Therefore, there is a need for an efficient and low-cost system to facilitate the evaluation of the serviceability of an existing road pavement surface. This paper introduces a newly developed road condition assessment system (called Ippo-Campo) and its practical application to road maintenance decision-making. Ippo-Campo is a pavement maintenance evaluation system, based on a moving vehicle and obtains data from a motion sensor, moving vehicle video, sound, and GPS data. It is a simple evaluation system that provides a systematic, consistent approach to the evaluation of the condition of a pavement surface. In addition, the video file produced by Ippo-Campo can be used for making a multi-criteria-based decision by using the analytical hierarchy process (AHP). It supports decision making with regard to complex sustainability issues and can help to recognize and define a problem in detail.

Th.2.C.6 11:35

New possibilities for concrete analysis 4.0 with the Laser-Induced Breakdown Spectroscopy (LIBS)

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In civil engineering the damage assessment of concrete infrastructures is an important task to monitor and ensure the estimated life-time. The aging of concrete is caused by different damage processes like the chloride induced pitting corrosion of the reinforcement. The penetration depth and the concentration of harmful species are crucial factors in the damage assessment. As a highly cost and time-consuming standard procedure, the analysis of concrete drill cores or drilling by wet-chemistry is widely used. This method provides element concentration to the total mass. In order to provide a method that is capable to detect the element concentration regarding the cement content only, the laser-induced breakdown spectroscopy (LIBS) will be presented. The LIBS method uses a focused pulsed laser on the sample surface to ablate material. The high-power density and the laser-material interaction causes a laser-induced plasma that emits elemental and molecular line emission due to energy transition of the excited species in the plasma during the cooling phase. As each element provides element-specific line emission, it is in principle possible to detect any element on the periodic table (spectroscopic fingerprint) with one laser shot. In combination with a translation stage the sample under investigation can be spatially resolved using a scan raster with a resolution up to 100 µm (element mapping). Due to the high spatial resolution, the

element distribution and the heterogeneity of the concrete can be evaluated. By using chemometrics the non-relevant aggregates can be excluded from the data set and the element concentration can be quantified and referred to a specific solid phase like the binding matrix (cement) only. In order to analyze transport processes like diffusion or migration the two-dimensional element distributions can provide deep insight into the transport through the pore space and local enrichments of elements. As LIBS is a multi-elemental method it is also possible to compare the ingress and transport process of different elements like Cl, Na, K, S, C, and Li simultaneously and evaluate cross-correlations between the ions. Furthermore, the element mapping allows to visualize the transport along cracks. This work will show the state of the art in terms of hardware and software for an automated LIBS system as well as different applications. Focus will be the application of LIBS for a fast concrete analysis.

Th.2.C.7 11:50

Long Term Skid Resistance of Exposed Aggregate Concrete Pavement

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Exposed aggregate and transverse tining concrete pavement have gained their popularity due to improvement of skid resistance. At early age, transverse tining concrete surface provided a better skid resistance than exposed aggregate surface. Transverse tining surface is composed of both binder and aggregate, however, cement binder is not durable as aggregate. Thus, skid resistance may be reduced due to the loss of cement binder when pavement ages. Additionally, aggregates angularity and wearing resistance have an importance role in pavements skid resistance. Exposed aggregates on the surface may also be polished and consequently the reduction of aggregate physical properties will decrease the skid resistance before the end of design life. Therefore, this research aimed to compare and quantify the loss of long term skid resistance of exposed aggregate pavement compared to transverse tining surface texture based on the data that was surveyed from the acceleration wheel testing in laboratory. Moreover, polishing resistance of various aggregates for exposed aggregate concrete was also evaluated.

Th.2.D | PRACTICAL APPLICATIONS AND CASE STUDIES (II)

Th.2.D.1 10:20

Long-Term Mode Shape Variations of Hagia Sophia with Environmental Factors

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Dynamic structural parameters depend on environmental factors such as temperature. Although cases documenting the effect of atmospheric conditions on natural frequency and damping are reported in the literature, studies on how mode shapes are changing over longer periods in the order of years are relatively rare. Mode shapes of historical buildings can be more complicated than of other structures. They are identified from vibration recordings obtained from structural monitoring systems. In this study, the mode shape variations of Hagia Sophia in Istanbul are examined using continuous recordings obtained between years 2013 and 2016. The modal frequencies of the structure are estimated by peak picking from Fourier amplitude spectra of 1-hour long windows. Mode shapes are calculated by Frequency Domain Decomposition (FDD) method. The variations in mode shapes are estimated for each window via the Modal Assurance Criterion (MAC) method, the Coordinate Modal Assurance Criterion (COMAC) and Enhanced Coordinate Modal Assurance Criterion (ECOMAC). Obtained MAC values for each window are combined to get the long term MAC variations and compared with those of environmental factors in search of any dependency between them. It was also possible to gain an understating of the range of variation of modal shapes over a time frame during which no known structural damage took place on the structure.

Th.2.D.2 10:35

First Application of Base Isolation in an Existing Residential Building in Istanbul

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Many existing buildings which have been constructed in the 70s and 80s in Istanbul, has been found to have inadequate capacity under seismic effects. The reason for such shortcomings are due to changes in design standards towards stricter criteria (higher return period earthquakes), as well as due to poor construction techniques, low quality materials and uncontrolled design and workmanship. The insufficiency is determined with careful examination, which includes site measurements, core testing, rebar surveys and computer-generated detailed models. After inspection, if the performance under gravity and seismic loads is unsatisfactory, retrofitting is required. Seismic protection through base isolation is an economic and efficient way to retrofit existing building structures. The alternative is a conventional, intrusive retrofitting, which requires strengthening at all floor levels.

For new built major structures, such as hospitals, schools and bridges, base isolation is a preferred and widely used method in Turkey. For new built structures, the placement of isolators is rather simple. However, for existing structures, the method requires the removal of a portion of the column, while under load, and its replacement with seismic isolators.

The tenants of a residential building (Gurup apartment) in Moda district of Istanbul, has decided to use base isolation as a seismic protection system. It is the first residential building to be retrofitted with base isolation in Istanbul. The structure is a reinforcement concrete frame structure without shear wall. The isolation system is applied at the basement floor, above the foundation level. It consists of 27 lead rubber bearings (LRB) and 6 sliding bearings under all columns. The columns are cut using a specially designed force transfer system, and the devices are installed at the removed concrete slice.

The acceleration limit above the isolation level is determined using a pushover analysis, taking the actual properties of the existing upper structure into account. The displacement and acceleration limits ensure that no strengthening is needed above isolation level. This brings comfort to tenants as access to building is uninterrupted during retrofitting, and all works are carried out at the basement. The

isolation system, installation method and its advantages is discussed in detail.

Th.2.D.3 10:50

GPS Performance Assessment and Analysis, El Carrizo and Juarez Bridge in Sinaloa Mexico

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It has been already proved in literature that several approaches using Global Positioning System (GPS) can be intelligently used for the performance evaluation of bridges. This paper is focused on GPS, since it naturally produces position estimates as compared to seismic or other instruments that record either velocity or acceleration, and thus, an integration is required. Hence, a research was conducted in order to evaluate the GPS capabilities in extracting the performance of two important bridges located at Sinaloa Mexico: (1) the Juarez Bridge in Culiacan, which is a reinforced concrete structure that connects two significant zones of the city and (2) the Carrizo Bridge one of the most important bridges constructed in the Mazatlan-Durango federal highway, which help to connect the Pacific Ocean with the Gulf of Mexico. For the GPS data processing scheme at Juarez Bridge, the authors used the traditional DGPS approach by means of the GAMIT/TRACK software, considering 1 and 100 Hz sampling rate in two separate experiments, 15-degree cut-off angle, ionosphere-free double-differenced (DD) carrier phase method. Additionally, for the Carrizo Bridge we used the CSRS-PPP GPS, representing an alternative previously reported to be effective in monitoring the structural performance of bridges, considering 10 Hz sampling rate and 10-degree elevation mask. Precise final orbits disseminated by IGS (International GNSS Service) and NGS (National Geodetic Survey) antenna calibration parameters were used. Based on the data processing, GPS time series were generated for the proper calculation of dynamic and semi-static displacement at both bridges. However, GPS displacements obtained in terms of coordinates may not accurately reveal the behavior of the bridge without considering prior filtering of the data. Hence, appropriate post-processing filtering was applied to the final displacements. It is expected that the results from the proposed research will provide enough information to characterize the dynamic behavior and provide information in order to calibrate mathematical models to detect damage and to address prognosis studies of both bridges.

Th.2.D.4 11:05

Long-Term Vibration Monitoring and Model Updating of Gageocho Ocean Research Station

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In order to study ocean and meteorological issues related to the climate change, Korea has been operating several ocean research stations (ORS) in remote ocean area including Ieodo ORS since 2003, Gageocho ORS since 2009 and Sochengcho ORS since 2014. In 2011, the Gageocho ORS was directly attacked by Typhoon Muifa and it was severely damaged to its structural members and several observation devices. After that, the Gageocho ORS was rehabilitated with 5 m heightening considering the 100-year extreme wave height, and the vibration measurement system was also instrumented to monitor the structural vibration such as acceleration and inclination and to assess the structural integrity of the Gageocho ORS. In this study, the modal characteristics of the Gageocho ORS were investigated using the long-term measurement data. As a result, natural frequencies of lower two bending modes and one torsional mode were reliably estimated as 1.79, 1.82, and 2.65 Hz, respectively. It was also found that the damping ratios in the first mode could be more consistently obtained with lower level of uncertainty when the acceleration response was larger. The damping ratio was estimated as about 0.7%. A preliminary finite element (FE) model was constructed using drawings and the several candidate FE models were manually built considering different structural conditions such as corroded thickness. These candidate FE models ware updated using the identified modal properties and the pattern search method which is one of the direct search optimization methods. The calculated modal properties from several updated FE models were compared, and the best model was selected by comparing the errors between estimated and calculated modal properties. Concludingly, it is expected that the present results obtained from long-term monitoring can be useful for establishing the essential database for jacket-type offshore structures and to assess the structural integrity of the Gageocho ORS.

Th.2.D.5 11:20

Crack monitoring in the Baptistery of the Euphrasian Basilica in Poreč

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In this paper we present six-month results of an ongoing structural monitoring of the Baptistery in the Episcopal Complex of the Euphrasian Basilica in the historic centre of Poreč, which is under UNESCOs protection as one of the best preserved complexes of early Christian architecture in the world. The complex is located by the sea and is partially still being used for its original function. Two wide and more than five meters long vertical cracks have been present for some time in the Baptistery, so the authorities decided to undertake a continuous crack width measurement. Automatic static monitoring system was installed with the aim to determine (i) if the cracks are active and (ii) if there is a correlation between the crack opening and the environmental parameters or the sea level oscillations. Such a continuous structural monitoring is a good way of getting necessary data in order to properly assess and extend the life time of heritage structures.

Th.2.D.6 11:35

Measured and computed dynamic characteristics of a hospital building in Bucharest

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The southern part of Romania is characterized by special soil conditions, i.e. thick soil deposits of Romanian Plain, leading to a long corner period of response spectra Tc=1.6s with associated large displacement demands in the Romanian Seismic Design Code P100-1 (2013). The stiffening approach to control the structural seismic

response may therefore not be successful but the alternative solution of base isolation is promising. The first step towards this solution is to properly estimate the dynamic characteristics of buildings. The reinforced concrete frame structure of a hospital built in 2014 in the capital city Bucharest is investigated. It has an underground level and five stories and its shape is irregular. Its elastic dynamic characteristics under small amplitude vibrations are estimated using multi-sensor ambient vibration measurements combined with classical spectral analysis. The results are compared with numerical results obtained from the computation of a structural model which are the basis for the optimum base isolator design within the next step of the research project.

Th.3.A | VISIONARY CONCEPTS, DEEP LEARNING

Th.3.A.1 13:30

Self-Prestressed Carbon-Reinforced High Performance Concrete Elements

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Prestressed high performance concrete (HPC) elements using tendons made of pultruded carbon fiber reinforced polymer (CFRP) were developed by Empa in late 90ies. With their low density (1.6 kg/m3) and very high strength (>2000 MPa), CFRP tendons perform in many aspects better than traditional prestressing steel tendons. This regards especially their practically complete resistance to corrosion. Use of CFRP tendons allows reducing the thickness of the concrete cover and hence the dimensions of the whole element. Another advantage of CFRP tendons are their excellent fatigue properties. Moreover, the tendons, unlike traditional steel, show practically no loss of prestress due to creep and relaxation. The interfacial bond between the CFRP tendons and the HPC is sufficient for transferring the prestress to the concrete and anchoring the tendons in the concrete during flexure after releasing the external anchorage.
While the mechanical properties and the durability of the CFRP tendons are unique, their prestressing technology is similar to that used with conventional steel. Typically a multi-purpose clamping anchorage system is used at both ends of each tendon to build-up and maintain the prestressing force until the concrete has hardened (pre-tensioning method). An external prestressing frame with massive steel beams anchored in the soil by means of concrete foundations is needed. Finally, hydraulic cylinders are also needed to prestress the CFRP tendons.
The innovative idea developed in this Empa project consists of using concrete that expands after setting and therefore induces tension in the CFRP tendon and compressive prestress in HPC, thereby eliminating the need of an externally-imposed prestressing and simplifying substantially the production process of the prestressed elements. This process is referred to as chemical prestress or self-prestress and was applied until now only to achieve minor prestressing levels of steel reinforcement. In this project, concrete recipes with a combination of expansive agent, an internal curing agent and a shrinkage-reducing admixture were developed. This family of expansive concrete allowed achieving levels of free and restrained expansion able to induce high and durable prestressing (>1000 MPa) in novel ultra-high modulus (460 GPa) CFRP tendons made of pitch-based carbon fibres. Finally results for self-prestressed concrete beams realized with this technology are presented, where the beams achieved bending strength and deformability under load comparable to conventionally prestressed beams.

Th.3.A.2 13:40

Automated Infrastructure Inspection based on Digital Twins and Machine Learning

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One of the key challenges in our modern society is the provision of safe transport infrastructure. Infrastructure managers are subject to regulations requiring major infrastructures to be periodically checked for damage before it becomes a safety hazard.
In the standard structural inspection, specially qualified civil engineers travel to the object to be inspected on site. Notes, sketches and photos are prepared for the subsequent report. The inspectors are introduced to non-directly accessible locations with special, heavy inspection equipment. During such a test the object is not or only partially usable, which leads to interruptions, delays, traffic jam and thus considerable non-availability costs.
In recent years, approaches of a drone-based structural inspection are increasingly noticeable. These are mainly limited to a visual inspection of the created optical images.
By using new technologies, a more objective and faster structural inspection can be carried out at a lower cost. In order to achieve the highest possible level of automation, the actual test is no longer performed on the real object, but on a digital twin of the construction. The assessment of damages and reporting is carried out automatically. All data can subsequently be further processed in the Infrastructure Asset Management programs or BIM programs. The solution consists of three subservices that perfectly match each other, enabling a complete inspection, assessment, report preparation and action planning in a much shorter time.
1. CREATION OF THE DIGITAL TWIN:
From the object to be inspected, thousands of images are produced in a highly automated manner using multispectral cameras. From these, an exact 3D model of the object is created with extremely high accuracy. This model represents the digital twin of the real object and could then conveniently be screened for damage from the office on a PC screen.
2. AUTOMATIC DAMAGE ASSESSMENT
Damage such as cracks, spalling, chloride content, moisture penetration, etc. are automatically searched for by means of artificial intelligence and possibly compared with the results of earlier investigations. All detected damage is marked on an automatically created 3D model and automatically summarized in a report. The assessment of whether a construction is still safe can be done with a greatly reduced amount of time.
3. CONNECTION OF FURTHER SERVICES:
The digital twin as well as the damages are available in common data formats and can be further processed as needed in otherapplications like BIM-Software.

Th.3.A.3 14:00

Reinforced Masonry Retention Wall Model Using Artificial Neural Networks

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The use of reinforced masonry retention walls has become widely spread in South America as a fast-built and relatively economical construction technique. Nevertheless, there exists no much information related to the behavioral characterization of this type of elements. Experimental results exhibit both a highly non-linear behavior and large dispersion of results since masonry cells are filled with flowable concrete of low resistance and their reinforcement is basically composed of small-diameter steel bars. In the framework of an experimental program, a set of reinforced masonry-wall strips were tested under flexure for different steel reinforcement ratios. The experimental results obtained were numerically simulated using inelastic-hinges (plastic displacement and lumped damage) with a non-linear kinematic hardening model. The characterization obtained through these numerical simulations allowed training and validation of artificial neural networks (ANN) models to obtain damage patterns and fragility curves. The results obtained by ANN are comparable to those obtained with the traditional statistical methodology, with the advantage that does not require complex mathematical formulation and the ability to find hidden patterns during the training phase.

Th.3.A.4 14:15

Modeling of Bimodulus Materials with Applications to the Analysis of the Brazilian Disk Test

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[1] Missouri University of Science and Technology, Rolla, USA; [2] University of Los Andes, Mérida, Venezuela

This work presents a modeling approach to assess the dependence of the bimodularity of the elastic properties on the mechanical response of specimens under Brazilian test conditions. For a representative description of the statistical nature of the material, the correspondence between the tensile and compressive moduli is supposed to be fully described by a joint probability distribution. Conveniently, a Gaussian copula function is used to generate the distribution that correlates the bivariate elastic properties by specifying marginal univariate distributions estimated from experimental outcomes reported in the literature. Monte Carlo simulations of disk-shaped specimens under diametrical compression using randomly selected values of the elastic modulus as input into a finite element program are conducted under identical loading and boundary conditions. The constitutive law is based on the plane-stress assumption. As an illustrative case, the proposed approach is used to provide insight into the effects of bivariate random parameters on the mechanical behavior of a white marble. Numerical results are compared to a previously developed analytical solution framed on the same modulus theory and to a deterministic numerical response based on mean values. The comparison between the numerical and theoretical analyses proved that the proposed stochastic scheme can effectively characterize the spatial variability of the mechanical behavior of bimodular materials.

Th.3.A.5 14:30

Artificial intelligence-based estimation of the consumed fatigue-related lifetime for an operating wind turbine support structure

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This work presents the perspectives on neural network application in fatigue lifetime estimation for a 0.5 MW wind turbine located in Dortmund, Germany. The wind turbine has been in operation since 1997, and the monitoring data was collected from 2010 to 2013 and is still being collected since 2016. Hourly fatigue damages for the whole monitored period are calculated from the displacement (strain) measurements at the tower and can be used for the remaining lifetime estimation. However, the fatigue damage that occurred during the unmonitored period can have a high influence on the accuracy of the remaining lifetime forecast. Therefore, a neural network is employed in order to estimate the fatigue damage for the unmonitored period. The calculated hourly fatigue damage is paired up with the available hourly wind data from several wind stations located in a 52 km radius and used to establish correlations (neural network training) between the wind data in the area and the strain based fatigue damage. In this way, an attempt has been made to estimate the wind induced fatigue damage. Since the hourly wind data is available for the whole operating life since 1997, the neural network is employed to estimate the hourly fatigue damages for the unmonitored period and a novel remaining lifetime estimation is given. The accuracy of the neural network is tested on a part of monitoring data, which is not used for the training and its efficiency is tested for two types of neural networks, feedforward neural network for fitting (FFNN) and Self-Organizing Map (SOM).

Th.3.A.6 14:45

Deep Learning-based Defect Detection and Assessment for Engineering Structures

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Recently, a lot of efforts were focused on implementing deep learning-based techniques for developing effective systems for automatic crack detection and segmentation with both good performance and low time complexity. Unfortunately, many of the studies used the image dataset that was homogenous and collected under controlled conditions, and didnt provide crack segmentation, which prevents the approaches from practical applications. Moreover, the network architecture was not flexible, thus, the model is robust for processing different datasets containing real-world or industrial images. In this paper, to provide an effective and useful defect (cracks and corrosions) identification (detection and segmentation), deep learning-based approaches are developed as an integrated framework for defect detection, segmentation, assessment and visualization using 3D reality mesh modeling technology. The robustness of these techniques is evaluated and demonstrated using real cases of the bridge structures, road pavement, and tunnel inspection. The results obtained show that the proposed framework is effective at and readily applicable to various engineering structures.

Th.3.A.7 15:00

Moving Beyond the Romans: Deep Learning and Road Maintenance

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A central challenge to maintaining roads that has existed since the Romans built the Appian Way over 2,000 years ago is regular, thorough inspection of the roads. Visual inspection was the inspection mode in ancient Rome and it is the most common method now around the world and not just for roads but for all large infrastructure. Fortunately, recent advances in both AI/deep learning and inexpensive but precise sensors has created the opportunity to transform the way infrastructure is monitored and maintained, with the result of lower insurance costs. The presenter will highlight the opportunities and challenges of deploying this technology not only through the example of RoadBotics but other companies assessing infrastructure. Roadbotics deep learning and standard smartphones to assess road surfaces and roadways. We were spun out of Carnegie Mellon Robotics Institute in 2016 and we serve over 100 cities in 16 US states and 4 countries.

Th.3.A.8 15:15

Application of deep learning-based crack assessment technique to civil structures

S. Cho [1], B. Kim [1], G. Kim [1]
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In this study, a deep learning-based automated crack detection technique has been applied to real structures. The deep learning model used in this study is a mask R-CNN model pre-trained with 200,000 COCO dataset, and a transfer learning is performed using training data collected from Internet and the other bridges. Various types of cracks are marked as ground truths on more than 1,000 images with 1000x1000 pixel resolution for the training, and they are used for the transfer learning. The trained model is developed to distinguish cracks from the concrete surface, especially against similar objects that exhibit color and contrast features similar to those of cracks. The developed model is applied to three types of civil structures, e.g., a bridge, a tunnel, and a concrete road, and the detection results are analyzed in depth using performance measures. Then, the detected cracks parts are further processed to assess the crack information such as crack width and length. The result shows that the carefully trained deep learning model can work as an effective alternative to the current visual inspection.

Th.3.B | STRENGTHENING, MONITORING AND LIFE-CYCLE ASSESSMENT OF METALLIC STRUCTURES (II)

Th.3.B.1 13:30

Full scale cast iron girders reinforced with CFRP – flexural testing

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This paper will report on the flexural testing of two cast iron girders from a demolished railway bridge in Scotland. The girders were about 150 years old and had been reinforced with ultra high modulus carbon fibre polymer composite (CFRP) in 2004. The CFRP on one girder had been damaged during the demolition and was rendered completely ineffective before testing. The girders were 9m long and were tested in four point bending to failure giving a unique opportunity to compare the behaviour of unreinforced and reinforced cast iron at full scale. After the flexural testing fragments were tested to obtain material properties. The tests showed the considerable benefits of CFRP strengthening and confirmed that the CFRP was fully bonded to the cast iron until close to the point of failure. The test results have been compared to the original design predictions. The paper will include details of the girders, the test rig and procedure and will discuss the benefits obtained from CFRP strengthening of cast iron girders.

Th.3.B.2 13:45

Smart SMA-based system for fatigue strengthening of cracked metallic bridge connections

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In this study, a new retrofit system is proposed to enhance the load-carrying capacity of double-angle connections in aged railway steel bridges. The double-angle connections between the stringers and the cross beams are normally prone to fatigue cracking owing to semi-rigid (not simple) behavior of the connection. The retrofit system includes activated Fe-SMA strips that pass over the top of the connection. Two Fe-SMA strips of 50 × 1.5 mm (width × thickness) are sandwiched inside the end anchorage systems that are mounted on the top flange of the beams in each side of the connection. The strips are then activated (pre-stressed) to maximum temperature of 260 °C. A new stringer-to-floor beam double-angle connection test setup was specially designed to examine the performance of the proposed system. Initially, a static test was performed on the connection without strengthening system. In this regard, an image correlation measurement system (ICS) was also used to measure the full-field displacements of the surface of the connection angle. In the next step, two high cycle fatigue (HCF) tests were performed on the non-strengthened and strengthened connection in a stringer-to floor beam framing in the test setup. It was observed that the fatigue life was enhanced substantially using the activated (i.e. pre-stressed) Fe-SMA strips. The activated Fe-SMA strips reduce tensile stresses (due to the reduction of moment on the connection) in the critical cracked detail in the steel connection, which is beneficial for fatigue life.

Th.3.B.3 14:00

Monitoring and control of the longest suspension bridge in Brazil during its complex rehabilitation process

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The iconic and centenary Hercílio Luz Bridge in Florianopolis was the first road link to be erected between the island of Santa Catarina and mainland. It has been closed to traffic due to safety reasons for more than 20 years after a crack was found on one bar from the suspension system. A major restauration project is on going with a planned opening to traffic by the end of 2019. This demanding work includes

the restauration and reinforcement of the foundations, metallic superstructure, bearing supports, eye-bars and suspension cables as well as the re-construction of the road deck and construction of new foot and cycle decks.
One of the most important parts of the project is the replacement of the whole suspension system, which involves a critical task of load transfer from the suspension cables to the temporary support structure. The combination of monitoring and control is essential on such cases where the age and design uncertainties increase the chances of unpredictable behavior. To support such task, a complex system with a large number of sensors was implemented for real time measurement of strain, temperature, inclination, wind and flow during the actuation of the elevating hydraulic jacks. Different sensor technologies were combined, including a large number Fiber Bragg Grating sensors (FBG).
On this article, the details on the contracted monitoring system, including hardware and software used to implement it, will be presented. The challenging installation of almost 300 FBG sensors performed in a record time of shortly more of than one month, which was a determining factor for the choice of technologies, will be shown. Data on the load transfer tasks to dismount the suspension elements will be exposed and compared with theoretical predictions.

Th.3.B.4 14:15

Experimental study on repairing of fatigue-cracked steel plates using high strength bolts and CFRP strips

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Nowadays, there are a large number of aging steel bridges producing the fatigue cracks under the fatigue loading. It is quite necessary to adopt appropriate repair methods to ensure the safe operation of the bridges and extend their service lives . The fatigue performance of precracked steel plates using various repair methods was experimentally studied in this work. The test specimens included four main groups: reference unstrengthened group, repaired group using only stop-hole method, high strength bolt stop-hole group and high modulus CFRP strips repaired group. Under the high cycle tension-tension fatigue loading, the failure mode and fatigue life of all groups were obtained. Moreover, the effectiveness of the strengthened steel plates was investigated. Experimental results reveal that the methods of high-strength bolt stop-hole repairing and the high modulus CFRP repairing have significant effects. In addition, high strength bolt stop-hole repairing method is slightly better than high elastic modulus CFRP repairing method.

Th.3.B.5 14:30

Experimetal research on durability of bonding reinforcement method for distortion-induced fatigue in steel bridges

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In order to ensure the service safety, rationally extend service life and maintenance interval, bonding steel angles reinforcement methodology was used for distortion-induced fatigue cracks at web gaps in steel bridges, featuring introducing no or less damage to the original structure. Full-scale fatigue tests were performed to evaluate the effectiveness and durability of bonding reinforcement. Test specimens were loaded to produce distortion-induced fatigue cracks, and then the girders were strengthened by bonding reinforcement method. After placed in the laboratory for about three and a half years, the reinforced specimens were continued to be subjected to cyclic loads. Test results indicated that the out-of-plane distortion and the stresses at the critical fatigue details sharply decreased, and fatigue cracks did not propagate after bonding strengthening. Therefore, bonding steel angle reinforcement technique has significant potential for controlling distortion-induced fatigue cracks at web gap regions in steel girder bridges effectively, and has good durability.

Th.3.B.6 14:45

Application of IRT for assessing the process of delamination of hybrid steel/FRP elements

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IRT (Infrared Thermography) has been used for a wide range of applications in Civil and Structural engineering including the analysis and assessment of structural members of a building with surface temperature as key parameter. IRT allows for detection of delaminated surfaces and assessment of the integrity of a structural member to an extent which cannot be seen by naked eye. Delamination of fibre reinforced polymer (FRP) laminates from a steel plate in a hybrid steel/FRP infill plate system contributes to a reduction in load capacity, and thus identification of location and extend of delamination is an integral part in assessing damage. The presented paper investigates, analyses and compares the experimental IRT results for different combinations of hybrid FRP and steel infill plates that are subjected to application of quasi static load following ATC 24 protocol. The obtained results will aid in estimating the delamination behaviour of hybrid steel/FRP infill plates in steel shear walls during the process of cyclic loading. Conclusions on the applicability of the use of IRT to identify the location and extend of delamination are offered.

Th.3.B.7 15:00

Mechanical behaviour of corroded prestressing steel strand

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Since the prestressed concrete structure was introduced, many cases on deterioration of the prestressing steel due to corrosion have been reported. Once the corrosion of the tendons is observed in existing bridges, engineers need to decide actions such as replacement, strengthening and repair according to the conditions. In this paper, hundred corroded prestressing steel steands were obtained from the existing prestressed concrete bridges and inspected. For the engineering decision, the mechanical properties of tensile strength and fracture strain according to section loss by corrosion were evaluated by tensile tests. Three different configurations of section losses were defined to stand for the corrosion shape for quantitative evaluation, and empirical equations of remained tensile strength and fracture strain were proposed with respect to the section loss. Based

on the observed behaviour of the corroded strands, equivalent analysis models of corroded strands were suggested for the evaluation of structural behaviour of prestressed concrete structures, and the model was verified by comparison to test results.

Th.3.B.8 15:15

Strengthening Effect of CFRP Bonded Steel Plate with Insufficient Bond Length

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As a repair and strengthening method for steel structures, a method of bonding CFRP with resin has begun to be applied. Generally, in CFRP bonding method, since the steel and CFRP are designed on the premise of behaving as a complete composite in section, the bonding lengths for transmitting loads are required on both sides of CFRP. In some cases, the required bonding length becomes longer due to the rigidity of the CFRP layer, the thickness and the shear modulus of elasticity of the adhesive layers. In addition, corrosion of steel bridges often occurs in narrow parts and complicated shapes parts, and in some cases, it is difficult to secure required bonding lengths on both sides of the section to be reinforced.
In this research, the authors focused on the case which the bond length of CFRP cannot be satisfied the required bonding length for complete composite in section. The tensile tests were conducted on the test specimens in which CFRP was adhered to a steel plate with insufficient bond length, and the influence of insufficient bond length on strengthening effect was investigated. In addition, the experimental results were compared with the theoretical value and the authors proposed the design method of the amount of reinforcement with insufficient bond length.

Th.3.C | SHM – SYSTEM IDENTIFICATION AND MODEL UPDATING

Th.3.C.1 13:30

Assessment of reinforced concrete structures performance under environment aggressiveness for durability monitoring

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An increasing number of systems and non-destructive techniques are being developed to evaluate the durability of reinforced concrete (RC) structures through parameters such as its pH or chloride contents. However, the determination of these parameters is not enough to estimate the remaining lifespan of existing structures, since corrosion and carbonation rates depend on different threshold values that may differ significantly from the standard values proposed for design purposes of new constructions. These thresholds vary with temperature, type of cement or environmental conditions (i.e. dry-wet cycles) of the structure, among others. Therefore, durability prediction models must also include the evolution of the performance of the structure subject to the aggressive action of various agents. In order to evaluate the evolution of the changing behaviour of an existing structure under aggressive environment, it is necessary to study all the information gathered from inspections, reparations, etc. of existing nearby structures. Thus, by identifying similar behavioural patterns and comparing them with the environment aggressiveness, location, type of cement, etc. of the structures associated to each pattern, it is possible to establish correlations between different data sources. Therefore, in order to calibrate a durability oriented monitoring system, it then becomes necessary to analyse the performance of the structure and not only the evolution of the external environmental aggressiveness. Only by combining those two approaches is it possible to design efficient durability monitoring smart systems of structures. In other words, it shall be possible to gather adequate information to make sound decisions on the management of the asset, that is, when and how to intervene within the context of a Management System. This paper focuses on the assessment of the evolution of RC bridges with regard to their performance under different environment aggressiveness through the analysis of Spanish Bridge Management Systems databases of different locations. Such databases contain more than 1,500 real cases of bridges inspected in different regions and climates, of different ages, typologies, and traffic conditions, which provide a sound basis to choose representative bridges to be monitored and, therefore, to adjust prediction degradation models.

Th.3.C.2 13:45

Monitoring Concrete Strength Parameters for Gravity Dam using Strain Energy Based Structural Health Monitoring Technique

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Monitoring of concrete strength parameter like Modulus of Elasticity during its phase of strength gaining is an important health monitoring strategy in order to comprehend its construction quality and overall health. On the other hand, reduction in concrete strength owing to the damage caused by fire, environmental agents, etc. also an important real-time observation - essential for regular monitoring of the structural health. Variation in the extent of the deviation for the intended strength parameter many a time calls for an appropriate and robust identification parameter for that specific case. In this article, four sets of vibration-based damage identification parameters such as Natural Frequency, Displacement mode shape (DMS), Curvature mode shape (CMS) and Strain Energy mode shape (SEMS) are employed to detect as well as to localize the zone of strength reduction. Numerically the method is applied to the finite element model of the Koyna concrete gravity dam. The model, prepared in ABAQUS commercial software environment, is validated with the available data. Analyzing the results it is inferred that natural frequency and DMS can detect the presence of damage or for that matter reduction in the strength but cannot localize the impaired elements or if at all not with adequate accuracy. Therefore, in case of strength gaining phase where the differential value of the strength parameter is significantly small, these two parameters are not the appropriate ones. While on the other hand, CMS and SEMS identify the strength difference up to the extent of localization. Among them, SEMS is found to be the most sensitive and therefore, the most appropriate parameter for initial damage or small strength deviation identification. In case of damaged structures for initial detection first three identification parameters are employable but for localization of damage at its premature state SEMS is the most suitable indicator. This method is applicable for updating the model using the modal parameters of the real structure obtained from the operational

modal analysis at the site. Therefore, real-time monitoring of the structure from its construction stage to the stage of performance is possible using SEMS as the monitoring parameter.

Th.3.C.3 14:00

A comparison of greedy and global searches for measurement-system design in bridge load testing

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Due to conservative design models and safe construction practices, infrastructure often has significant yet-unknown reserve capacity that greatly exceeds code requirements. Reserve-capacity assessments lead to better asset-management decisions through either avoiding unnecessary replacement or lowering maintenance expenses. Field measurements have the potential to improve the accuracy of model predictions. To fulfil this potential, measurements, must be associated with an adequate structural-identification methodology. Error-domain model falsification is an intuitive model-based methodology that explicitly represents systematic uncertainties that are typically associated with structural models. Additionally, model-updating outcomes depend on the design of the measurement system. Engineers usually select sensor types and place sensors based on experience and signal-to-noise estimations. The development of more rational strategies for measurement-system design has recently received research attention. Quantitative sensor-placement strategies differ either in the objective function for sensor placement or in the optimization algorithm used. This study presents a comparison of greedy-search (hierarchical) and global-search (such as genetic algorithm or Probabilistic global-search Lausanne) methodologies in terms of joint-entropy evaluations, recommended sensor configurations and qualitative characteristics using a full-scale test study, the Rockingham Bridge (Australia). Results show, for low number of sensors, that global-search algorithms only slightly over-perform the greedy-search algorithm in terms of information gain. However, this is at the expense of a longer computational time compared with greedy search. Nevertheless, global-search strategies provide other advantages such as finding multiple near-optimal sensor configurations. These advantages are illustrated sung the full-scale bridge case.

Th.3.C.4 14:15

Traffic and Temperature Effects Monitoring on Bridges by Optical Strands Strain Sensors

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Knowing the actual effects of traffic and temperature on a bridge and its consequences in terms of stress cycles in the bridge structure is of great value in the scheme of a resilient asset management. A solution is proposed in the case of different types of road bridges in Europe, based on continuous strain monitoring by the mean of Optical Strands sensors and of dedicated analysis tools provided by OSMOS Group.
The choice of performing continuous strain measurements on critical parts of the bridge is discussed, as a relevant solution in order to provide the control of the actual effects of traffic, wind and temperature on the structure and the assessment of the structural elements in terms of strain and stress, both under the effects of the live loads and over the long term.
As the monitoring device is conceived as a permanent solution for these bridges, the accumulated data over several months allow a statistical analysis of the effects of heavy traffic and relevant anomaly detection from several criteria at different time scales: dynamic behavior, stability of the response to temperature changes, long-term stability under the effects of the dead load after thermal correction.
The monitoring of bridges through continuous high-sampled strain measurements over long periods as proposed by OSMOS is an integrated solution which answers to several different problematics, both for the daily management through detection of overweight vehicles, and for the long-term assessment through lifespan estimation and anomaly detection.

Th.3.C.5 14:30

Structural Health Monitoring results as an input for asset management of offshore wind turbine support structures

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For an accelerated shift from fossil-based energy sources to renewable energy sources, being environmentally friendly only is not enough. The renewable energy sources need to be competitive with the other energy sources in cost and reliability. For the case of offshore wind energy industry, multiple studies showed that significant cost reduction can be achieved from minimizing the operation and maintenance (O&M) costs.
Optimized O&M strategies depend on reliable and continuous information on the structure condition and performance. Most of the already operating or planned offshore wind farm projects worldwide are or will be equipped with Structural Health Monitoring (SHM) systems to ensure structure safety. In Germany, the equipment of SHM system on 10% of the structures in an offshore wind farm even used to be a government requirement. The available SHM data represent an enormous and as of yet largely unexploited potential for optimization of asset management and wind farm operation.
In this paper, SHM data analysis results from operating offshore wind farm projects are used for evaluation and quantification of unfavourable operation conditions or scenarios.

Th.3.C.6 14:45

New SHM applications in cable-supported bridges – Case studies

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As the technical capabilities of structural health monitoring (SHM) continue to increase rapidly, the benefits and added value it can bring to bridge construction and maintenance projects around the world also increase accordingly as does the use of such technology as more and more bridge industry professionals become convinced of the added value SHM can bring to their projects. This is especially true of cable-supported bridges and other complex structures, where the potential benefits and value of using a suitably designed SHM system, for short-term assessment or long-term monitoring

purposes, are particularly compelling. It is therefore informative to gain insights into current applications from time to time, helping to stay abreast with the rapidly developing technology. This paper shall describe current SHM applications on cable-supported bridges that have recently started providing data or that are expected to in the coming months, providing an insight into the value they bring to the projects or structures on which they are used.

Th.3.C.7 15:00

What added value can SHM bring to my construction project or structure maintenance programme?

M. Treacy [1], N. Meng [1], A. Paciacconi [1], T. Richli [1]
[1] Mageba SA, Bulach, Switzerland

Although the numerous benefits of using modern structural health monitoring (SHM) technology in the construction of bridges and other structures, and for subsequent inspection, maintenance and renovation work, are well established, they are not fully understood or appreciated by many with responsibilities in these fields. Even engineers that have used SHM in the past may fall within that category, considering the rapid rate of development of SHM technology in recent years. This paper shall seek to address this by highlighting key benefits offered by the use of SHM in such work, as opposed to relying on traditional manual inspection and assessment methods. These include, for example: verification of structural performance as designed; optimization of maintenance of key structural components; detection of long-term structural deterioration and extension of service life; and the immediate notification of critical information by automated warning systems and how this can enable a structure for which risks have been identified to remain in service. It should also be recognized, of course, that the use of SHM can provide far superior inspection coverage (continuous rather than sporadic), with key variables measured at a much higher degree of sensitivity and precision, at significantly lower cost and that these advantages result in a much improved level of reliability. It is hoped that this paper will thus increase awareness of such risk-reduction and efficiency-enhancing benefits among those with responsibility for the construction, maintenance and renovation of bridges and other structures, and encourage them to give due consideration to the use of modern, appropriately specified SHM technology in their future work.

P1

Val-LIBS: A novel attempt to decipher the transport processes in concrete – A case study

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In order to evaluate the status of concrete structures, the advance of several potentially damaging processes needs to be evaluated. In Europe, one of the most common damaging mechanisms is the chloride-induced corrosion of the concrete-reinforcement or of prestressed concrete e.g. due to the usage of de-icing salt on the streets during the winter. In this context, multi-storey car parks are a highly valuable kind of building because a mixture of salt and snow is sticking to the car and after entering the warm car park, this mixture drops down resulting in a massive salt entry. Of course, such salt entries can hardly be prevented but what can be detected is the concentration and depth of the chloride entry into the concrete in order to assess if the concrete-reinforcement is possibly attacked by chloride-induced corrosion. A promising method is the so called laser-induced breakdown spectroscopy (LIBS) which is attributed by a high spatial resolution (generating 2D data maps in the µm range), precision (down to 0.1 wt.-% Cl) and measuring velocity (ca. 30 minutes per measurement). The Valtest AG (Lalden in Switzerland) is the first industrial building material testing laboratory using the LIBS technique for measuring the chloride concentration quantitatively in drill cores from concrete-made buildings. Here we present results obtained from measuring campaigns in multi-storey car parks across Switzerland. The results reveal that the Cl concentration are highly variable within each drill core underlining the need of using high spatial resolution methods to quantify the Cl entry. As LIBS allows the user to measure several elements simultaneously, we also investigated the carbonatization of the drill cores and first preliminary results indicate that the Cl concentration and the carbonatization front are running counter to each other. Such effects can only be resolved with high spatial resolution methods such as LIBS.

P2

Corrosion Damage Mode Testing and Damage Cause Analysis of Sodium Hypochlorite Concrete Tank Structure for Coastal Nuclear Power Plant

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Large-area cracking and spalling was found and severe corrosion and exposure of rebar occurred in the walls that seriously affected sodium hypochlorite storage tanks usability and durability. Visual surveys were firstly carried out to ascertain the corrosion damage testing contents and corresponding techniques. Non-destructive &micro-destructive testing techniques including half-cell potential technique and electromagnetic induction technique were used for on-site macro-level corrosion damage cause testing and analysis. Microscopic analysis including SEM and EDS techniques were adopted for concrete corrosion product micromorphology analysis and element content analysis in laboratory. The results show that the corrosion damage mode is the internal rebar corrosion leading to the concrete expansion cracking and spalling. The root corrosion damage cause is construction errors leading to areas with low concrete cover to reinforcement. The direct corrosion damage cause is variation in the coastal exposure environment leading to areas with elevated chloride ion content and high carbonation depth. In view of the causes of corrosion damage, relevant technical suggestions for concrete corrosion protection techniques and strength measures are put forward from the aspect of concrete damage mechanisms.

P3

Numerical Investigation of RC Beam Strengthened with UHPFRC Layers Using Cohesive Surface Bonding Method

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Ultra high performance fiber reinforced concrete (UHPFRC) is a smart concrete material that possesses very high strength, modulus of elasticity, ductility, and excellent durability characteristics because of its very dense homogenous microstructure. Due to the excellent performance of UHPFRC, it can be used as an alternative material for strengthening and retrofitting of the partially damaged or undamaged reinforced concrete (RC) structures for restoration or augmentation of the load-bearing capacity. In the recent years, several experimental and numerical investigations have been carried out pertaining to strengthening of RC beams using UHPFRC as retrofitting layers. Most of the researchers simulated the rebars in their finite element models (FEMs) using a 2-noded linear 3D-truss element and considered the contact between steel and concrete as perfect bond. In this study, an alternative 3D finite element model was developed using ABAQUS and the bond between the rebars and concrete was modeled using cohesive surface interaction method, which was found to be a better approach for bond simulation. The results obtained using the 3D finite element models developed in this study were matched well with the experimental and numerical data obtained from the previous studies.

P4

Repairing and strengthening steel-corroded RC members using the cathodic protection and by mounting a stainless steel rebar

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The authors studied the construction method of repairing and strengthening in the smallest procedure for the RC members which deteriorated by the steel rebar corrosion at the almost same time. At first, main reinforcement of RC beam was corroded by an electrolytic corrosion method. Then, the deteriorated RC beams were repaired in the electrolytic protection method by supplying a power supply to the titanium ribbon mesh which mounted into the near surface of the RC beam. Afterwards, these beams were strengthened by mounting a stainless steel rebar in the groove which was made in construction of electrolytic protection method. The corrosion protection current was turn on electricity for those specimens for approximately one month. Since then, the authors carried out a loading test for all specimens, and to examine the flexural behavior. As a result, even if it was not repaired the damaged cover concrete, the authors showed that it did not greatly affect the electricity behavior of the corrosion protection current. In addition, the embedment length of

the stainless steel rebar was influenced to the failure behavior by bond splitting.

P5

Smart electronic helper for long-term monitoring of bridges and building structures

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Increasing traffic volume on the one hand and ageing infrastructure on the other hand have created many new challenges for maintenance and structural health monitoring of roads and bridges. In the past, many bridges and road structures have been neglected, often resulting in traffic congestion, road closure, and increased repair costs. This research is concerned with the development of a system to improve the challenge of maintenance and early detection of damage, particularly moisture penetration and corrosion of steel reinforced concrete components. The objective is to develop a method that will also work after 30 years and longer. Many new IoT (internet of things) solutions are equipped with internal storage elements (accumulators or batteries) which are inappropriate here, since most relevant signs of degradation occur after decades, where the functioning of such sensor elements are more than questionable. The presented technology approach uses radio-frequency identification (RFID) and enables connectivity to sensors. It offers the advantage of an indirect and passive, completely independent energy supply without any energy storage components. Since the system should be permanently embedded in concrete, it is crucial to develop a long-term stable device which is adapted to the environmental influences of the structure, e. g., long-term resistance in very alkaline environment of 13 pH. In numerous experiments, the robustness of the system was tested and evaluated. Various tests with encapsulations to protect the electronics were performed, and for long-term validation different concrete specimens were instrumented with RFID-sensor-systems. Their operating time is now around two years and investigations for signs of fatigue and damage to the encapsulation and the electronics are ongoing.

P6

Application of Time Series Methods on Long-Term Structural Monitoring Data for Fatigue Analysis

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Structural health monitoring (SHM) can be employed to reduce uncertainties in different aspects of structural analysis such as: load modeling, crack development, corrosion rates, etc. Fatigue is one of the main degradation processes of structures that causes failure before end of their designed lifetime. Fatigue loading is among those variables that have a great influence on uncertainty in fatigue damage assessment. Conventional load models such as Rain-flow counting and Markov chains work under stationarity assumption and they are unable to deal with the seasonality effect in fatigue loading. Time series methods, such as ARIMA (Auto-regressive integrated moving average), are able to deal with this effect in the data; hence, they can be helpful for fatigue load modelling. The goal of this study is to implement seasonal ARIMA to prepare a load model for long-term fatigue loading that can capture more details of the loading scenario regarding the seasonal effects in traffic loading.

P7

Statistical approach-based automated determination of an optimal subset size for digital image correlation analysis

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This paper proposes an automated subset size determination algorithm for Digital Image Correlation (DIC) analysis. DIC is one of the popular analysis techniques for measuring minute structural deformation by comparing between the reference and deformed images. To achieve the reliable DIC analysis, the subset size determination is a critical issue. The subset should be large enough to contain distinguishable features, but the larger subset size typically leads to the larger analysis errors. However, its optimization has been highly depended on the experts experiences. To automate the optimization process, the statistical approach-based subset size determination algorithm is newly proposed in this paper. First, a correlation coefficient ratio indices are automatically computed to evaluate the subset matching reliability between the two images, i.e. the reference and deformed images, by increasing the subset sizes. Then, the optimal subset size is determined by employing the 95 % confidence interval of Gaussian distribution. The proposed algorithm is experimentally verified using metallic specimens covered with random speck pattern.

P8

Acoustic Emission and damage monitoring in RC beams under cyclic loading

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In the field of structural engineering, there is a great interest at developing non-destructive testing (NDT) methods intended to monitor the health condition of existing reinforced concrete elements, either due to the modification of their service loads, the occurrence of an accident or if their service life is wanted to be extended. In these scenarios, the usual practice is to carry out a load test to assess their structural capacity. In the last decades, new damage qualification criteria based on cyclic load tests and Acoustic Emission (AE) technique have been proposed in the scientific literature. However, there is still not enough experimental data to validate those acceptance criteria even more if considering the existence of different failure modes and new concretes. This work investigates the mechanical and AE responses of two real-scale concrete beams reinforced with steel rebars and fibers tested in four-point bending. Two rebar configurations were considered: one with shear stirrups, and the other with double area of tension reinforcement and without stirrups.

A loading procedure characterized by two load/unload cycles for each incremental load step until failure was used, and during the whole process the AE and the main mechanical parameters were continuously monitored. The failure behavior and the ability of several indices based on AE parameters to evaluate the damage level are analyzed.