INTERNATIONAL SOCIETY FOR STRUCTURAL HEALTH MONITORING OF INTELLIGENT INFRASTRUCTURE

The Monitor

Sreenivas Alampalli, Ph.D., PE, MBA, FSHMII, Editor-in-Chief
Nancy J. Cohen, MPA, SM, Managing Editor

Letter From Editor-in-Chief, Sreenivas Alampalli

Dear Society Members and Colleagues;

Most of you may be aware of the devastation caused by the Hurricane Sandy in the northeastern United States with particularly severe damage in the New York and New Jersey areas. Even though transportation structures did not suffer much structural related failures, the storm did cause significant damage to roadways and buildings due to flooding. Most notable was the power failure due to breaking of power lines and trees as well as flooding of the underground cables. The climate changes over the years have increased the number of natural disasters costing billions of dollars in damage. In response to these events, it is important not only to focus on recovery, but also on future prevention. Changes in the building and other structural standards may be required sooner than later. Structural health monitoring can play a major role in developing these standards by measuring actual demands on the structures, structural response to extreme events, and then estimating risk from these quantitative measurements. I invite your ideas on this subject for the next two issues of *The Monitor* to be published in 2013.

Recently, I gave a presentation to graduate students at The State University of New York in Buffalo, NY on SHM from a practitioner's perspective. At the end of the presentation, several simple questions were posed that were very difficult to answer. Below are sample questions raised by the students:

- How many sensors do I need to monitor a simple structure?
- What kind of sensors do I need?
- What is the cost of the sensors? Where can I find them?
- Where can I get SHM data to use for projects or test my models?
- Where can I find cost data of SHM projects?

In order to develop the future engineering professionals, I believe it is our responsibility to have tutorials or articles that can answer basic questions about SHM and also to work towards establishing a database of SHM data. ISHMII can play a major role in further improving this field. If you can contribute an article written specifically to help graduate students improve their understanding of SHM, please send them for publication in *The Monitor*. If you have any suggestions or ideas on establishing a database of SHM data for use by students, please let us know.

This issue has seven interesting articles from around the world.

Durability of bridge decks is important in ensuring uninterrupted mobility and minimizing the life cycle cost of bridges. Thus, bridge owners are increasingly considering the use of epoxy coated and steel rebars in bridge decks. The article by Anil Agrawal and Abhishek Singhal briefly describes a long-term SHM project to evaluate the effectiveness of these rebars in extending the bridge deck durability.

Post-tensioned tendons in concrete bridges have the potential for deterioration due to corrosion. The evaluation of such deterioration has been very difficult. Use of multiple nondestructive tests and careful analysis by experienced personnel is generally required to determine the health of such bridges with tendons exposed to corrosion activity. The article by Satrajit Das details such a study containing both field and laboratory tests. Use of built-in passive sensors during construction of such long and complex bridges to monitor and evaluate corrosion activity may be very useful in the future and should be considered by owners based on careful benefit-cost analyses.

The article by Jon Watson and Terry A. Tamutus details the use of an SHM system on a 50-year old post-tensioned segmental viaduct in the UK to detect wire breaks, identify the corresponding tendon group, and its location within 500 mm. The article shows value of such system on major bridges as part of a comprehensive asset management plan that includes visual inspection and sensor based monitoring system working together to assure safety and maintain required level of service.

Long-span complex bridge instrumentation is becoming common due to the benefits offered by monitoring in making effective maintenance and repair decisions. The initial and maintenance costs of monitoring systems can be relatively small, if designed carefully, compared to construction and maintenance costs of such big complex bridges. The article by Yufeng Zhang, Xinzheng Liang and Litao Zhang of Jiangsu Transportation Research Institute Co., China, describes a good example of the use of such systems during normal operations of their bridges. An interesting item to note is that the number of sensors varied considerably from 55 to more than 500 depending on the bridge. It will be of interest to get more information on this variability from the authors in a future article.

Dorotea Sigurdardottir and Branko Glisic describe an instrumented pedestrian bridge on the Princeton University campus that has been used as an on-site laboratory for educating both undergraduate and graduate students. This project shows value of cooperative efforts between researchers and practicing engineers to foster knowledge on innovative monitoring methods while serving the owners need for better management systems.

With advances in computing and sensor technologies, high volume data collection is becoming more prevalent than before. Innovative data analysis technologies, to minimize data transmission times and to accommodate unintended gaps in the data, are important in such cases. Yuequan Bao, Hui Li, and Jinping Ou describes one such method “compressive sensing sampling" in their article with three examples.

Finally, we have a non-bridge article by Rupert Zischinsky describing cost effective monitoring of hydroelectric plants in Austria. This article shows balanced use of visual inspections, experienced expert personnel, and automatic monitoring for cost-effective operation of infrastructure. This interesting article also shows that irrespective of state-of-the-art modern equipment, one needs human involvement for certain applications and also for reacting to unexpected emergency situations.

In closing, on behalf of *The Monitor* team, Nancy and I wish you all a happy holiday season and a prosperous New Year to you and your families.

Sreenivas Alampalli

Sreenivas.Alampalli@dot.ny.gov

Inside *The Monitor*

CSHM-4 SPONSORS

GERMAN
SOCIETY FOR
NON-DESTRUCTIVE
TESTING

ISHMII thanks the German Society for Non-Destructive Testing and BAM Federal Institute for Materials Research and Testing for co-sponsoring CSHM-4, held in November in Berlin, Germany, and extends appreciation to BAM for hosting the Workshop.

The Silver Sponsors of CSHM-4 recognized here are:

Hottinger Baldwin Messtechnik GmbH's product range covers sensors, transducers, strain gauges, amplifiers and data acquisition systems as well as software for structural durability investigations, tests and analysis. The potential fields of application can be found in every branch of engineering and industry in both virtual and physical test and measurement. HBM has 27 subsidiaries and sales offices in Europe, America and Asia and representatives in 40 countries around the world.

NPO SODIS develops structural monitoring technologies for buildings and construction safety, geotechnical monitoring, anti-terrorist safety systems, building operation systems, and civil defense engineering arrangements for the prevention of emergency situations. Bolotnikovskaya st., 11/1, Moscow, 117556, Russian Federation.

Sylex, a designer and manufacturer of fiber optic passive products, manufactures sensors and interrogators (read-out unit) typically used in Civil Engineering and Geotechnical markets that are based on FBG fibers using unique DTG technology applicable for strain, temperature, displacement, pressure, load, vibration and soil deformation measurements. Mlynské luhy 3, 821 05 Bratislava, Slovak Republic

The Bronze Sponsors are:

Advanced Solutions GLÖTZL

NATIONAL INSTRUMENTS

RESEARCH REPORTS

USA

Continuous Corrosion Monitoring of a Reinforced Concrete Bridge with Epoxy-Coated and Stainless Steel Clad Rebar

Anil K. Agrawal, Ph.D. and Abhishek Singhal, Department of Civil Engineering, The City College of New York, New York, New York

Corrosion of reinforcing steel in concrete structures is one of the most expensive problems facing civil engineers in the United States. The cost of repairing or replacing deteriorated structures could be more than $20 billion annually and the cost is rising every year. The New York City Department of Transportation (NYCDOT) sponsored a corrosion monitoring project on the newly-constructed deck of Annadale Road Bridge in Staten Island, New York, through the Innovative Bridge Research and Construction (IBRC) program of the Federal Highway Administration (FHWA). The bridge deck was constructed using both epoxy-coated and stainless steel clad rebar, providing an opportunity to compare their long-term anti-corrosive properties. The main objective of the monitoring is to understand the corrosion of the rebar, including the initiation of corrosion and anti-corrosive properties of epoxy-coated and stainless steel clad rebar. To achieve this, 109 sensors designed to measure corrosion and corrosive environment around the rebar were installed in the rebar cage of the bridge deck (see the photos below). The study is expected to provide detailed knowledge on the (i) initiation and propagation of corrosion in reinforced concrete bridge decks, (ii) evaluation of key factors influencing corrosion, and (iii) study of anti-corrosive properties of epoxy-coated and stainless steel clad rebar.

The Annadale Road Bridge is a single span steel multi-girder bridge with a span length of 16.5 m and is 18.3 m wide. The reinforced concrete deck of the roadway is 240 mm thick with an integral wearing surface. The construction started in March 2009 and finished in September 2010. The installation of a majority of the sensors was carried out in two phases. During Phase I, corrosion monitoring sensors were installed in the half of the bridge deck that used epoxy-coated rebar. Installation of sensors and pouring of concrete in the bridge deck for this phase was completed in October 2009. In Phase II, sensors were installed in the half of the bridge deck containing stainless steel clad rebar, a project completed in June 2010.

In addition to vibrating wire strain gauges and thermocouples, three types of corrosion monitoring sensors were installed in the bridge deck: V2000 corrosion monitoring probes (shown above), corrosion penetration rate monitoring probes (CPMP) and embedded corrosion instruments (ECI-1). These sensors are distributed in both halves of the bridge deck, in numbers and locations, to compare the corrosion performance of the reinforcing rebar.

Monitoring data has been collected for the epoxy-coated rebars since October 2009 and since July 2010 for stainless steel clad rebars. The data demonstrated that corrosion hasn't started yet on both epoxy-coated and stainless steel clad rebars. Data from all 109 sensors will be collected for the next several years and will be analyzed to develop a detailed knowledge-base on corrosive behavior of two types of rebar.

Acknowledgments: The project has been supported through collaborative efforts of the FHWA Administration, New York State Department of Transportation (NYSDOT) and NYCDOT. In particular, the authors acknowledge the support of Dr. Kolluru Subramaniam (Professor, Indian Institute of Technology, Hyderabad, India, and formerly of the Department of Civil Engineering, The City College of New York), Dr. Sreenivas Alampalli (NYSDOT), Lawrence King (Senior Vice President of HAKS, New York, and former Deputy Chief Engineer, NYCDOT), and Henry Perahia, Nazim Khan, Mansur Khan, and Atiq Rehman, all of NYCDOT.

Questions and comments regarding this project may be directed to Dr. Anil K. Agrawal at agrawal@ccny.cuny.edu.

USA

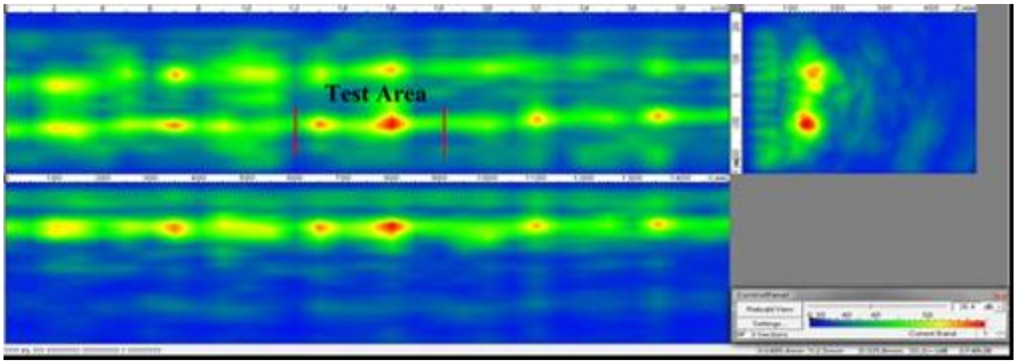
Corrosion Evaluation of Post-tensioned Tendons in the Segmental Concrete Box Girder Spans of the Albemarle Sound Bridge in Washington County, North Carolina

Satrajit Das, Ph.D., P.E., WSP USA

The Albemarle Sound Bridge is located on North Carolina State Highway 32 between US 64 and Edenton. Constructed in 1991, the overall length of the bridge is 5.6 km and is comprised of three sections: 2.57 km south trestle spans, 1.8 km north trestle spans and 1.22 km approach and main span units connecting the north and south trestle spans. The superstructure is comprised of precast segmental post-tensioned box girders for the approach and main spans and post-tensioned slabs for the trestle spans. The scope of this project included the evaluation of the approach and main span box girders for a total of thirty-one spans.

GPR used to locate rebar and internal tendons (left) and tomographer used to detect voids in tendon ducts (right)

The corrosion evaluation process began with a review of the available structural drawings of the bridge. A series of non-destructive tests, in conjunction with limited destructive testing, served as the backbone for this evaluation process. For internal tendons that are fully embedded in the concrete, ground penetrating radar (GPR) with a high frequency antenna was used to identify the actual tendon profiles inside the top slab. The internal tendons were located on the piers and other segments in a banded fashion from the top side of the deck. Sounding (tapping) of the external post-tensioning ducts were conducted end to end over their exposed length to determine the presence of voids inside the duct. Deterioration associated primarily with corrosion and/or other related factors, if any, were documented. All voids were documented with their location by tendon number and distance from the nearest reference bulkhead. Internal tendons were subjected to ultrasonic tomography to detect voids or other irregularities in the internal post-tensioning ducts. Test locations were selected either from the vicinity of the high points or from areas where signs of corrosion, cracking, moisture, damage, internal voids, or irregularities were found.



Tomograph showing a potential hot-spot inside a metal duct carrying internal post-tensioning tendons

Once the test locations were identified, the surrounding concrete (as applicable), the duct and the grout from the test areas were removed for a length of approximately 46 cm for conducting field tests and for collection of concrete powder or grout samples for subsequent laboratory testing. A battery of field and laboratory tests such as pH, half-cell potential, electrical continuity tests on reinforcement, and chloride, moisture and sulfate content were performed on these samples. Scanning electron microscopy was performed to determine the microstructure of the grout. A concurrent deck evaluation was performed by measuring concrete cover over rebar at all core locations and extracting concrete cores from each of the thirty-one spans. In addition to petrographic examination, the deck cores were tested and analyzed for chloride content, chloride diffusion rate and carbonation. The delamination survey was limited to the areas where coring was to be performed. Based on the analysis of test data, the corrosion condition of the post-tensioning tendon is currently being evaluated. Similar projections are being made for the deck based on cross-section loss, the rate of corrosion, and the projected future corrosion activity of the rebar.

A Report of Findings based on the results of field and laboratory testing is being prepared for the North Carolina Department of Transportation.

More information is available from Dr. Satrajit Das at satrajit.das@wspsells.com.

UNITED KINGDOM

Integrated Post Tension Wire Break and Structural Health Monitoring of the A4 Hammersmith Flyover

Jon Watson and Terry A. Tamutus
Mistras Group, Princeton Junction, New Jersey, USA

Hammersmith Flyover, constructed in 1961, is one of the earliest examples of a post-tensioned segmental viaduct in the UK. Managed by Transport for London (TfL), it carries a high volume of traffic, including heavy goods vehicles. The superstructure consists of three meter long triple-cell spine box beam units alternating with 300 mm cantilever diaphragm units, which also support pre-cast road slab units. The longitudinal post-tensioning consisted of two sets of four tendons of 16, 19-wire strands either side of the two internal webs encased in in-situ grout boxes.

A detailed special inspection was carried out during the 1980s and assessments made of actual section losses that were found by exposing the tendons at critical locations. These were used in a three-dimensional finite element load assessment model to determine the flyover's live load capacity. The results showed that despite the evident corrosion, the structure passed full 40t highway loading.

Visual inspections at a limited number of locations did not provide the TfL with the confidence that they understood the structure's condition. TfL needed to know whether the deterioration was continuing and, if so, at what rate. The decision was made to install a structural health monitoring system (SHMS). TfL's specification was demanding. It required a system to detect wire breaks through a high level of background noise and identify the individual tendon group and location within 500mm. TfL also required information on the movement of the roller bearings, some of which showed signs of corrosion due to flooding of the bearing pits, since resistance to movement could induce unwanted forces in the superstructure, continuous monitoring of deflections of each span and measurement of strains across critical segment joints.

Mistras Group was awarded a contract to design, manufacture, install and commission an intergrated SHMS to meet their specifications. The SHMS combines acoustic emission wire break sensors, displacement transducers, resistance strain gauges, inclinometers, and thermocouples with networked total stations and prisms along the length of the flyover all linked to computer systems located at the east end of the flyover with climate control and battery back-up. With more than 450 sensors, it is the largest bridge monitoring system in the UK. Installation commenced in April 2010 and took 8 weeks, with a further 2 weeks for testing and calibrating.

Post Tension Wire Break Monitoring: Acoustic Emission wire break monitoring was deployed over the east side of the flyover (nine spans) in 2011 and the west side (six spans) in 2012 to detect and triangulate wire breaks linearly and define the location to a specific tendon groups. Detection of the wire breaks uses the signature data collected during third party trials and those detected on other structures. The distinct signature and signal transmission from breaks allows automatic detection and instantaneous wire break alerts. Once installed, the wire break system operation was verified by cutting a single exposed wire in a blind test. The SHM located the break to within 100mm.

In December 2011, during planned tendon break-out and visual work at specific hot spot locations identified by the AE wire break monitoring, significant deterioration to the post tensioning was found. This effective visible inspection was only possible due to the AE monitoring as the cables could be fine in one place but 100mm away in very bad condition. This resulted in the emergency closure of the flyover while further investigations, propping and strengthening was organized. In January 2012, with contingency bridge propping in place, a single lane was opened east and west, with a 3 tonne weight limit and speed restrictions. Emergency strengthening with the internal post tensioned cables was installed with the structure reopened.

Not only will the monitoring warn of significant changes in the condition of the structure, but using the results of the special inspection and load assessment as a baseline condition, the results will be incorporated into the structural assessment model to inform decisions regarding the future management of the structure. They will enable TfL to develop a deterioration model to predict where and when future intervention or intrusive visual investigations may be required and also provide valuable information about the effectiveness of any works done to the structure to improve its durability. The monitoring will continue to be part of TfL's asset management plan to maximize the safe operational life of Hammersmith Flyover and to ensure the remediation work has the desired effect on the structure.

Comments and discussion may be directed to Terry Tamutus at (609) 468-5737 or terry.tamutus@mistrasgroup.com and to Jon Watson at 44 (0) 1954 231 612 or jon.watson@mistrasgroup.co.uk.

CHINA

Su-tong Yangtze River Highway Bridge

Structural Health Monitoring of 6 Long-span Bridges on the Yangtze River

Dr. Yufeng Zhang, Dr. Xinzheng Liang and Dr. Litao Zhang
Jiangsu Transportation Research Institute Co., Ltd (JSTRI), Nanjing, China

In recent years, a large number of structural health monitoring systems (SHMSs) have been established in conjunction with the large-scale construction of long-span bridges in China. These systems can monitor the responses of bridges in real-time under various environmental conditions, which provides important information for design validation, construction control, safety operation, and maintenance management of these bridges. Therefore, the SHMSs are playing a more and more important role in modern long-span bridges.

Research and Development team (left) and Commissioning (right)

[Jiangsu Transportation Research Institute Co., LTD](#) (JSTRI), the component unit of "Key Laboratory of Long-span Bridge Health Monitoring and Diagnosis Technology of the Ministry of Transportation China," has already undertaken the design, construction and operation of the SHMSs on more than 10 large bridges, including 6 long-span bridges across the Yangtze River. The SHMSs of these Yangtze River Bridges are described briefly in the chart below.

Type and Span of the Bridges

Name of the Bridge		Bridge style	Main span (m)	Location
Su-tong		cable-stayed	1088	Jiangsu (Suzhou-Nantong)
Jiang-yin		suspension	1385	Jiangsu (Jiangyin-Taizhou)
Runyang	south-branch	suspension bridge	1490	Jiangsu (Yangzhou-Zhenjiang)
	north-branch	cable-stayed	406	
Nanjing	south-branch	cable-stayed	628	Jiangsu (Nanjing)
	north-branch	continuous beam bridge	90+3×160+90	
Chong-qi		steel-continuous girder	102+4×85+102	Jiangsu (Qidong-Chongming)
Ma-an-shan	south-branch	3-tower suspension	2×1080	Anhei (Ma-an-shan)
	north-branch	3-tower cable-stayed	2×260	

Jiang-yin Yangtze River Highway Bridge *Chong-qi Yangtze River Highway Bridge*

Runyang Yangtze River Highway Bridge South Branch (left) and North Branch (right)

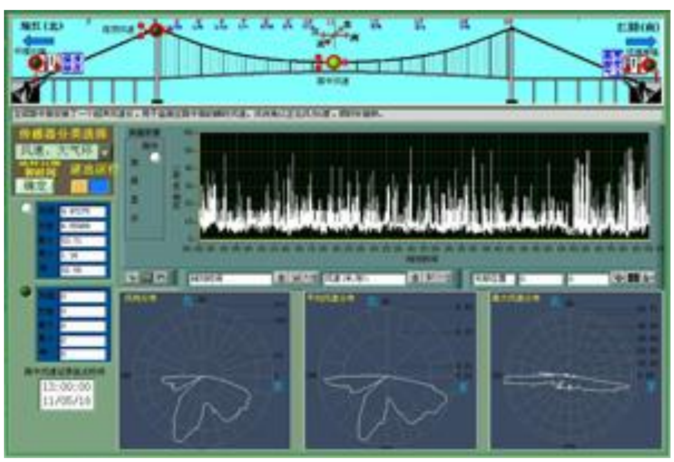
Ma-an-shan Yangtze River Highway Bridge South Branch (left) and North Branch (right)

Nanjing Yangtze River Second Bridge

System Design

The SHMs of these bridges on the Yangtze River include 4 subsystems: sensors, data acquisition and transmission, data processing and analysis, and structural state assessment. The details of the sensor types and numbers installed on each bridge are listed in the following table.

Type of the Sensors		Su-tong	Jiang-yin	Chong-qi	Ma-an-shan	Runyang	Nanjing
Acceleration		28	35	47	80	100	18
Strain	Resistance type	211		72			
	Vibrating string type	96					
	Fiber grating		80		268	120	
Barometer			1				
Displacement		8	4	4	6	2	8
Deflectometer				9	15		
GPS		4+1	8+1		8+1	8+1	4+1
Clinometer		6			2		
Anchor Cable Transducer					6		
Microwave vehicle detector							2
Corrosion		22					
Temperature Sensor in Structure		169	36	48	52	44	12
Temperature Sensor in Pavement							2
Temperature Hygrometer in Air		12	2	6	2	6	6
Anemometer		4	4	2	2	2	2
Total:		561	170	188	442	283	55



Analysis of wind data

Given the data obtained by the systems, JSTRI is able to carry out the structural health diagnoses of the bridges. As an example, during the trial operation in June 2005 after an upgrade, the SHMS of Jiangyin Bridge gathered a large quantity of data, including wind, temperature, overall displacement, beam-end displacement, acceleration, and strain. According to the data analysis, there was damage to the expansion joints. This was found and then a timely replacement was performed, which avoided the further development of the damage. And, two accidents where ships collided with the bridge were also identified using the real-time monitored data. Additionally, the data collected during several typhoons and traffic jams was used to evaluate the structural safety of the bridge under both of these extreme loading conditions.

More information can be obtained by contacting Dr. Yufeng Zhang at kolya@21cn.com.

USA

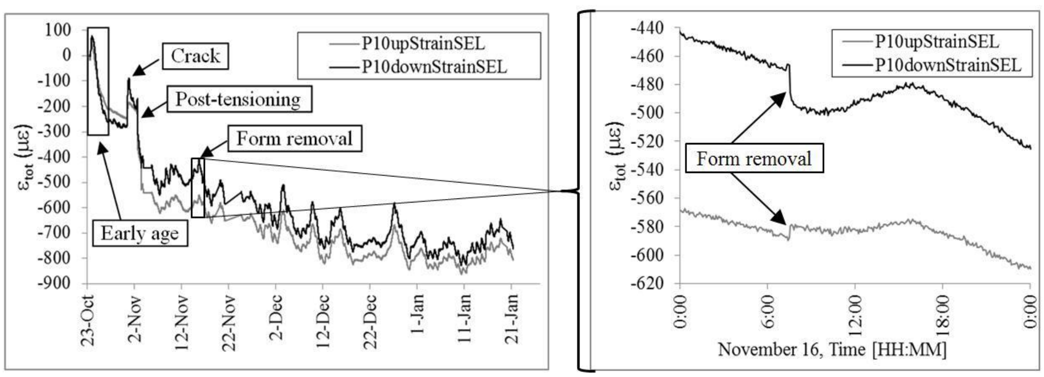
Streicker Bridge: An On-site Laboratory on the Princeton University Campus

Dorotea H. Sigurdardottir and Branko Glisic, Ph.D.
Department of Civil and Environmental Engineering, Princeton University

Streicker Bridge is a pedestrian bridge on the Princeton University campus completed in 2010. The geometry of Streicker Bridge is rather intriguing. Its main span is a deck stiffened arch that spans 34 m. The deck is post-tensioned concrete and the arch is weathering steel. The approach legs, also post-tensioned concrete, are continuous girders supported by steel columns. They are curved in plan and the main span cross-sections follow that curvature providing lateral stability. The whole structure is very slender; the arch diameter is 25 cm and the maximum depth of the deck is 60 cm. The elaborate geometry and slender elements both contribute to a complex structural system.

The Structural Health Monitoring Lab (SHMlab) in the Department of Civil and Environmental Engineering has transformed the bridge into an on-site laboratory for research and educational purposes. The bridge is currently equipped with two monitoring systems: a global monitoring system based on discrete fiber optic strain and temperature sensors (fiber Brag-grating – FBG) and an integrity monitoring system based on distributed sensing (Brillouin optical time-domain analysis – BOTDA). Both types of sensors are embedded in the concrete deck. The long-gauge FBG sensors are located at the most stressed locations along half of the main span and the south-east legs. In most locations there are two sensors, one at the top of the cross-section and one at the bottom. Each FBG strain sensor is equipped with a temperature sensor for temperature compensation. The BOTDA sensor is in the longest span of one of the approach legs.

The bridge has been monitored continuously since the pouring of the concrete, providing valuable information about the early age of the concrete as well as the first years of the structural behaviors while in service. The figure immediately below shows the total strain for one cross-section at the early age of the structure. Events such as the curing of the concrete, thermal cracking, post-tensioning and form-removal have been detected.

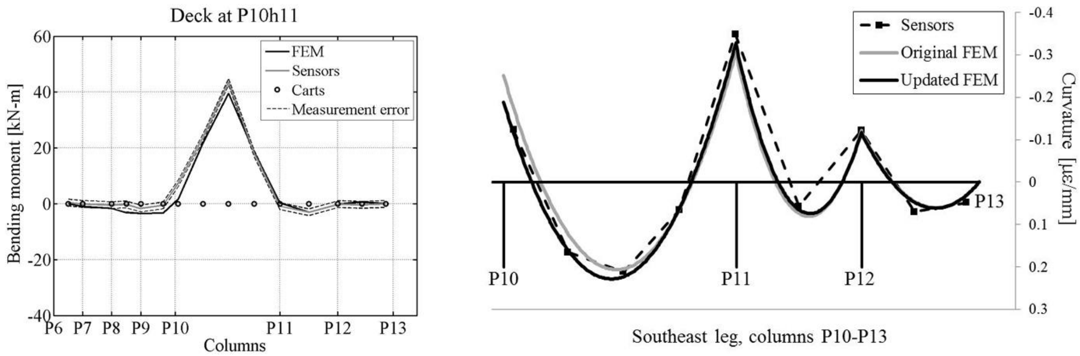


Total strain for the first months in the bridge life. Multiple events are detected (Source: Sigurdardottir et al., 2012).

The figure below illustrates the total strain and temperature at another location in the main span for the whole life time of the bridge.

Total strain and temperature for the three years since the pouring of the concrete.

Data from the monitoring system has also been used to assess the bridge performance and validate novel structural identification and damage detection methods in on-site conditions. Two snapshots of these studies are shown below. The figure on the left shows a bending moment influence line as movable system of forces (wheels of golf carts) is driven over the bridge compared with an FEM simulation of the test. This study was used to determine the stiffness of the cross-sections at the time of the test. The results also provided valuable information about the global structural behavior of the bridge (not presented here).



Two examples of studies done on Streicker Bridge. Left: influence lines, right: removal of the formwork (Source: Sigurdardottir et al., 2012).

The figure on the right illustrates procedure for model updating and damage assessment – the load from the removal of the formwork was used to estimate the reduction of rotational stiffness of a joint affected by early age cracking.

Streicker Bridge is the central topic of two senior theses, three master theses and a Ph.D. dissertation. These studies deal with post-tensioning, early age cracking, form removal, thermal and dynamic effects, long-term strain analysis, and load testing. The bridge continues to serve as an on-site laboratory for the SHM*lab* at Princeton University. The vast variety of valuable information on true structural behaviors that can be extracted by the monitoring system keeps steadily growing as the structure ages and the database expands.

For additional information, please contact Dr. Branko Glisic at bglisic@princeton.edu or Dorotea H. Sigurdardottir at dsigurda@princeton.edu.

Acknowledgements: This project has been realized with great help, and kind collaboration of many professionals and companies. We would like to thank Steve Hancock and Turner Construction Company; Ryan Woodward and Ted Zoli, HNTB Corporation; Dong Lee and A.G. Construction Corporation; Steven Mancini and Timothy R. Wintermute, Vollers Excavating & Construction, Inc.; SMARTEC SA, Switzerland; Micron Optics, Inc., Atlanta, GA. In addition the following personnel, departments, and offices from Princeton University supported and helped realization of the project: Geoffrey Gettelfinger, James P. Wallace, Miles Hersey, Paul Prucnal, Yanhua Deng, Mable Fok; Faculty and staff of Department of Civil and Environmental Engineering and our students: Maryanne Wachter, Jessica Hsu, George Lederman, Jeremy Chen, Kenneth Liew, Chienchuan Chen, Thomas Mbise, Peter Szerzo, Allison Halpern, Morgan Neal, Daniel Reynolds, David Hubbell, Pedro Afonso and Daniel Schiffner.

CHINA

Emerging Data Technology in Structural Health Monitoring: Compressive Sensing Technology

Yuequan Bao, Ph.D., Hui Li, Ph.D., and Jinping Ou, Ph.D.
Center of Structural Monitoring and Control, School of Civil Engineering,

Harbin Institute of Technology, Harbin China

Compressive sensing (CS), also called Compressive sampling, provides a new sampling theory to reduce problems associated with data acquisition that is sparse and where compressible signals can be reconstructed exactly from highly incomplete random sets of measurements. CS is widely used in many fields including digital cameras, medical imaging, remote sensing, seismic exploration and multimedia hybrid coding, communications. In 2007, MIT released the research of Baraniuk and Kelly about their CS-based camera as one of its ten emerging technologies. Here, the authors introduce three of the applications of CS in SHM that they have completed in recent years as a contribution to the evolving discussion of CS.

Data compressive sensing approach for data acquisition in structural health monitoring:

In SHM of civil structures, data compression is often needed to save the cost of data transfer and storage that results from the large volumes of sensor data generated from the monitoring system. In this case, we investigated the potential use of CS for vibration data compression; the acceleration data was collected from the SHM system on the Shandong Binzhou Yellow River Highway Bridge (right) and is used to analyze the data compression ability of CS. The results of the analysis show that CS can reconstruct the compressed signal well, so the CS algorithm can be integrated into an analog-to-digital converter to acquire the compressive data directly, in contrast to the traditional data compression methods.

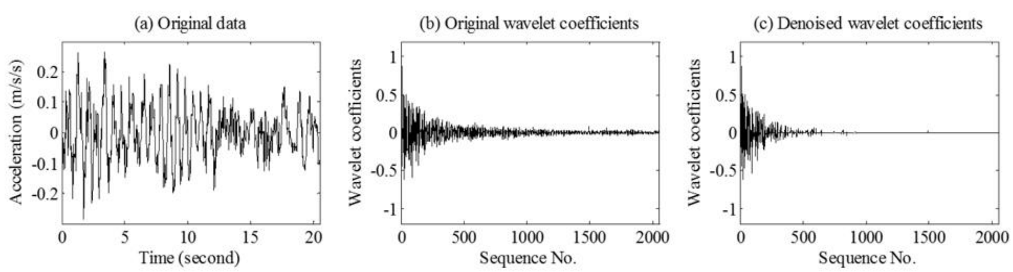


Fig. 1. (a) Acceleration response of bridge deck measured by accelerometer 13; (b) Original wavelet coefficients; (c) Denoised wavelet coefficients.

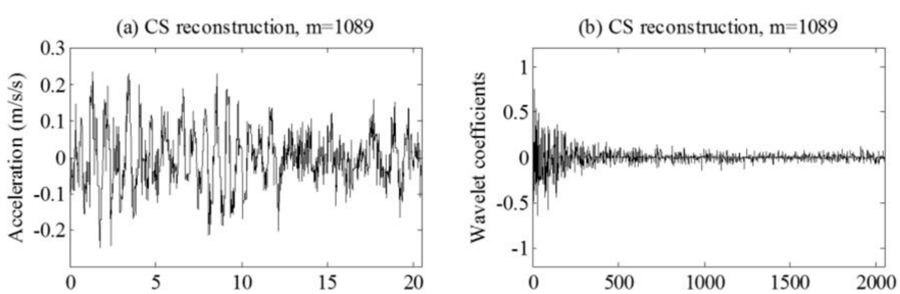


Fig. 2. CS results of acceleration data with m = 3s = 1089: (a) CS reconstruction data (b) The wavelet coefficients of (a)

Recovery of lose data for wireless sensors networks by using compressive sensing

approach: In a wireless sensor network, data loss often occurs during the data transmission between wireless sensor nodes and the base station, which decreases the communication reliability in wireless sensor network applications in civil SHM. Errors caused by data loss inevitably affect the data analysis of the structure and subsequent decision-making. Here, we investigated a novel application of CS to recover lost data in such a wireless sensor network. The main idea in this approach is to project the transmitted data from x onto y, where y is the linear projection of $\mathbf{x}$ on a random matrix. The data vector y is permitted to lose part of the original data x in wireless transmissions between the sensor nodes and the base station. After the base station receives the imperfect data, the original data vector x can be reconstructed based on the data y using the CS method. The flowchart of the approach is shown below. The acceleration time series collected by the SHM systems on the Jinzhou West Bridge are employed to validate the accuracy of the proposed data loss recovery approach. One of the results is shown below and indicates that good accuracy during the data recovery can be obtained if the original data has a sparse characteristic.

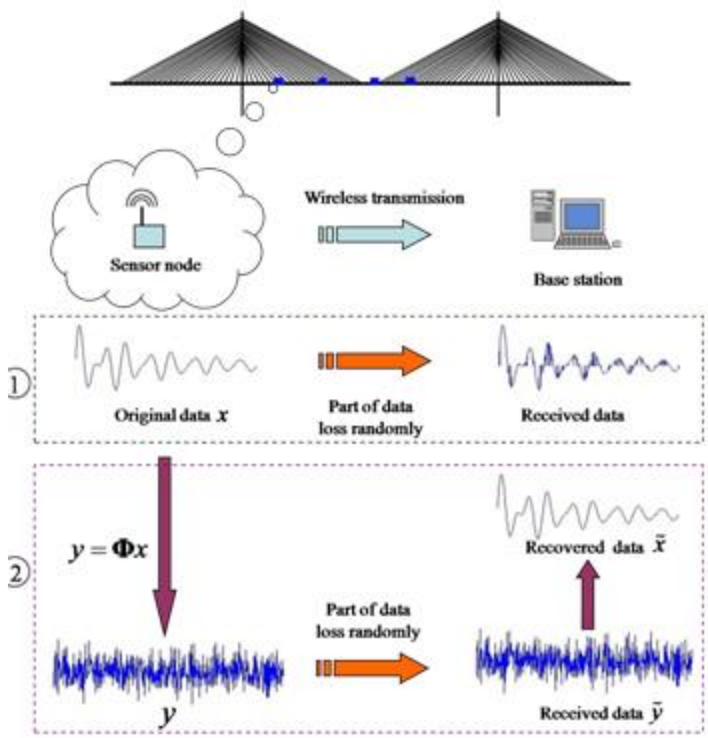


Fig. 3. Flowchart of the data loss recovery approach

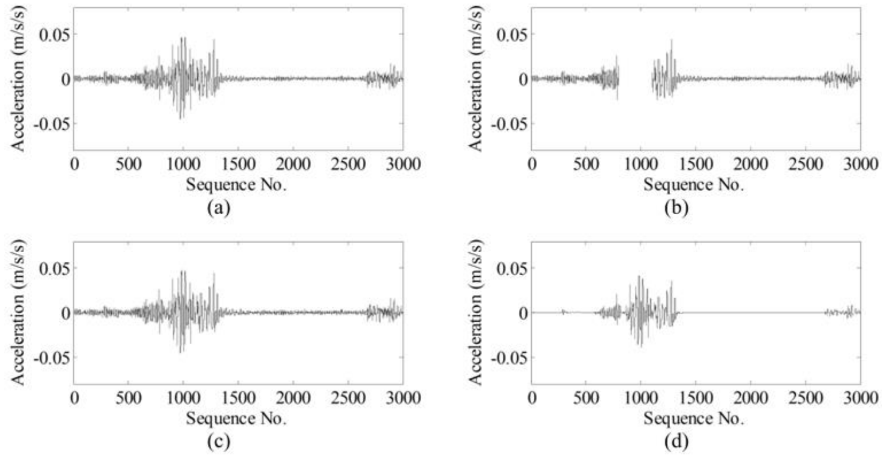
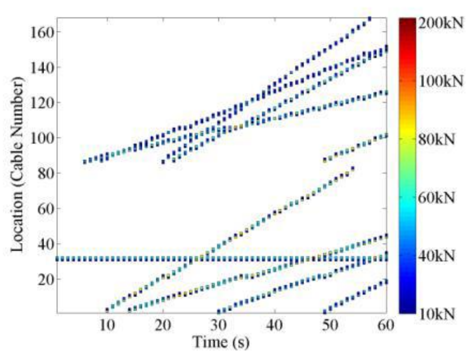
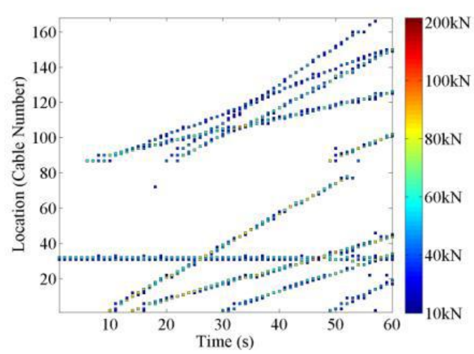


Fig. 4. Data recovery with 10% continuous packets loss: (a) original data; (b) original data with a 10% data packets continuous lost; (c) recovered data with a reconstruction error; and (d) de-noised recovery data with a reconstruction error.

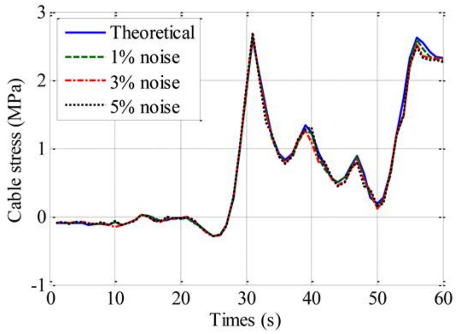
Identification of spatial distribution of vehicles on cable-stay bridges by using CS approach: In this research, we proposed a moving loads distribution identification method for cable-stayed bridges based on a CS technique for obtaining sparse signal representations for underdetermined linear measurement equations. CS is employed to localize the moving loads of cable-stayed bridges through limited cable force measurements. First, we presented a vehicle-bridge model for a cable-stayed bridge. Then, the relationship between the cable forces and the moving loads was established based on the influence lines. With a hypothesis of a sparse distribution of vehicles on the bridge deck (which is practical for long-span bridges), the moving loads are identified by minimizing the '*l*2-norm' of the difference between the observed and simulated cable forces caused by the moving vehicles penalized by the '*l*1-norm' of the moving load vector. The resultant minimization problem is convex and can be solved efficiently according to CS theory. A numerical example of an actual cable-stayed bridge is proffered to verify the proposed method. Figure 5 is the identification results for ten cars. The results show the feasibility of the method. The robustness and accuracy of this identification approach are validated.



5.a



5.b



5.c

Fig. 5. Identified moving loads and locations with 1% noise for ten cars: (a) real locations; (b) identified vehicle locations; (c) Cable force variation caused by moving vehicles of Cable 40 for ten cars

Please address questions to Dr. Yuequan Bao at baoyuequan@hit.edu.cn, Dr. Hui Li at lihui@hit.edu.cn and Dr. Jinping Ou at oujinping@hit.edu.cn.

AUSTRIA

Cost Effective Monitoring of Hydro Power Plants in Western Austria

Rupert Zischinsky, Vorarlberger Illwerke AG

Vorarlberger Illwerke AG operates more than 10 large storage power plants in Vorarlberg, the western province of Austria. Construction and operation of these facilities requires a wide range of monitoring activities mainly due to authority and in-house regulations. The focus of the monitoring tasks lies on the dams of large alpine reservoirs, penstocks and machinery in power houses in descending order. This is because of the enormous potential for catastrophic damage that a dam failure would cause to the densely populated valleys in the region. (Pictured above: Kops Dam.)

Because of authority regulations and to maintain the actual high level of security, a reduction in monitoring tasks is almost impossible. Since the monitoring costs are mainly driven by personnel costs, cost reduction is possible by increasing the efficiency of the deployed personnel. During the past 15 years Vorarlberger Illwerke AG has taken various measures to reduce the amount of personnel needed. Many monitoring systems have been automated and the work flow for non-automated systems has been considerably improved. Until now, it was possible to cut the labor costs more than 40%, while keeping the actual high security level.

The monitoring tasks involve geodetic methods but also mechanical and electrical sensors like plumbs, inclinometers and many more. Mechanical and electrical sensors can easily be automated, whereas automation for geodetic methods is more complex. GPS systems can only be used in open sky-situations, while trigonometric systems require clear line of sights with little refraction effects. There are other problems: narrow valleys limit the open sky, frequent dense fog and heavy rain block lines of sight, and bad refraction conditions when measuring over cold water present difficulties for the automated geodetic systems. Nevertheless, trigonometric systems are used to monitor smaller pump storage reservoirs 24 hours a day. They are also used to temporarily monitor machinery like heavy duty cranes inside power houses. The results for the indoor applications are very satisfying, while the outdoor systems operate at a status that is just sufficient.

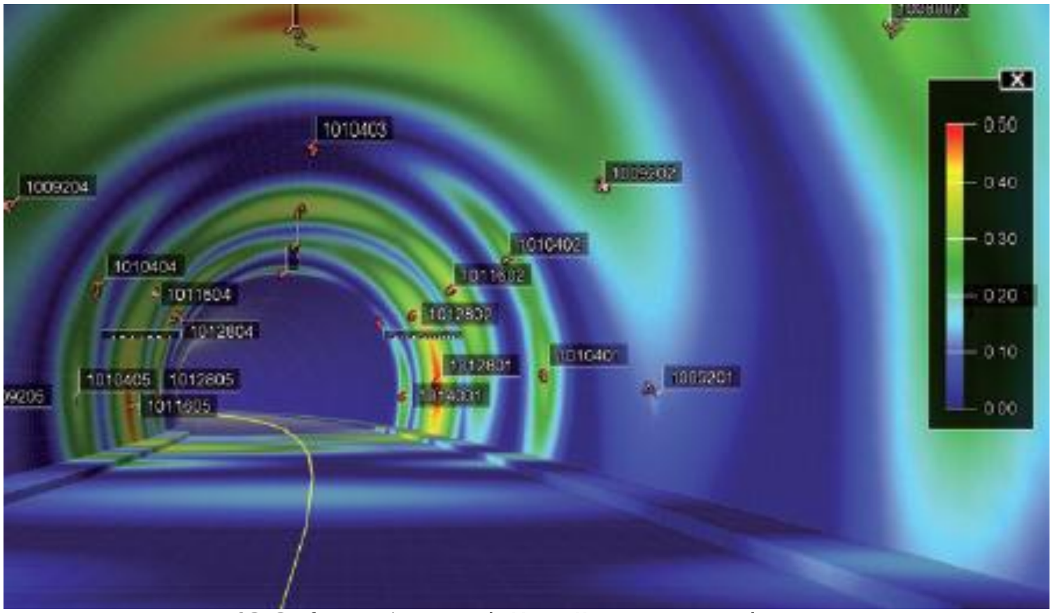
Automated trigonometric monitoring: Rodund II, power house crane (left)
Rodund I, reservoir dams (right)

Motorized high precision total stations, digital levels and dual-frequency GPS reception with choke ring antennas ensure quick and precise measurements even at instrument setups, which are physically hard to access.

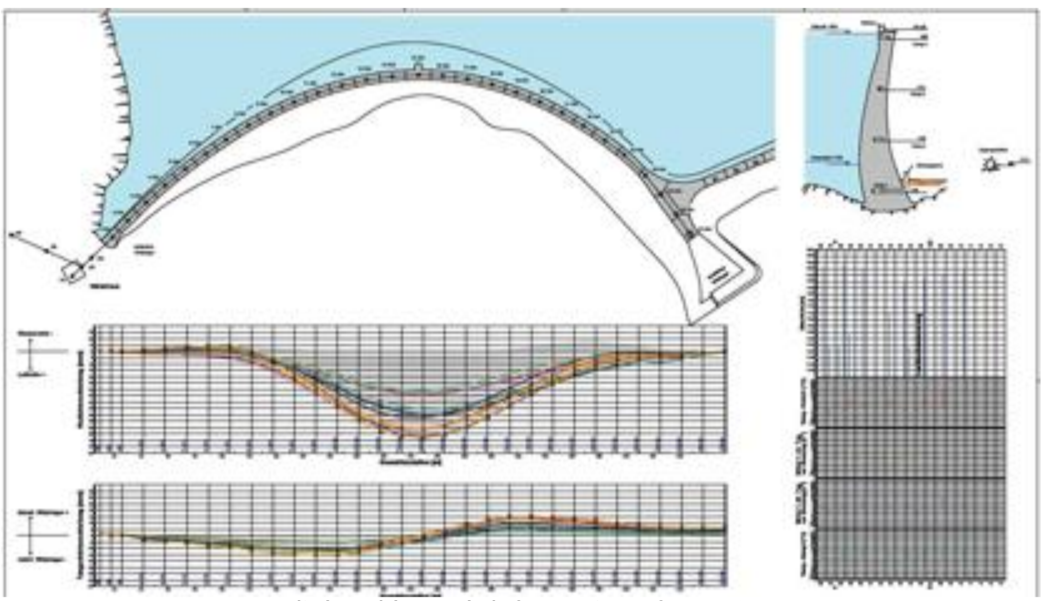
Trigonometric measurements Lünersee penstock

All measurement procedures are based on predefined configurations supported by individualized software applications on-board the instruments, minimizing the actual measurement times and the number of personnel involved.

An automated data stream from the instruments to the calculation software has been state of the art for many years with almost no further possible improvement. However, the situation is different for the display of deformation results. Easy to read diagrams, including drawings that show the position of the measured deformation points as well as 3D-deformation graphs are the key to a quick and reliable interpretation of the deformation values. The productions of these graphic outputs would usually require CAD-Software and a lot of manual work. To minimize the manual efforts, Vorarlberger Illwerke AG uses the specialized deformation software Axis3D that stores all deformation results in a database and produces meaningful graphics from user-defined digital forms. With this highly efficient tool, 38 different ready-to-plot deformation graphs can be produced within 6 minutes.



3D-Deformation graph Kops II access tunnel



Radial and lateral deformation of Kops Dam

Vorarlberger Illwerke AG invests considerable sums to maintain the state-of-the-art measurement equipment and software in order to minimize labor costs. Nevertheless, all the measures mentioned above still require a reasonable number of well-trained and experienced survey personnel, able to handle a wide range of different geodetic methods and to deal with frequently occurring unexpected situations.

Please direct your comments and questions to Mr. Rupert Zischinsky at [rupert.zischinsky@eratos.at.](mailto:rupert.zischinsky@eratos.at)

CREDITS AND ACKNOWLEDGEMENTS

The Monitor gratefully thanks its authors and contributors and acknowledges the following work. Photographs and graphics in each article were supplied by the authors with the following exceptions:

Photographs of corroded rebar shown in *Continuous Corrosion Monitoring of a Reinforced Concrete Bridge with Epoxy-Coated and Stainless Steel Clad Rebar*: http://scatechnology.com/gallery.html#!prettyPhoto[last_added]/0/ and http://www.kryton.com/in-the-news/2008/12/16/protecting-against-steel-corrosion/

Photographs of Hammersmith Flyover in *Intergrated Post Tension Wire Break and Structural Health Monitoring of the A4 Hammersmith Flyover*: http://www.fesi.org.uk/fesi-news.html and http://www.flickr.com/photos/tonybill/6690721163/

Photograph of the Shandong Binzhou Yellow River Highway Bridge in *Emerging Data Technology in Structural Health Monitoring: Compressive Sensing Technology*: http://en.ccccltd.cn/business/infrastructureconstruction/railway/201011/t20101112_1518.html

The full reference in *Streicker Bridge - An On-site Laboratory on the Princeton University Campus* is: Sigurdardottir, D.H., Glisic, B., Park, P. 2012. Streicker Bridge: Learning through Structural Health Monitoring. In proceedings: *EACS-5, June 18-20, 2012, Genoa, Italy*.

MEMBERSHIP UPDATES

A SPECIAL OFFER FOR FULL & CORPORATE MEMBERS

Renew Your 2013 ISHMII Membership
at 2012 Rates through January 3, 2013

Individual Membership at $125
Corporate Membership at $350 (4 individuals)

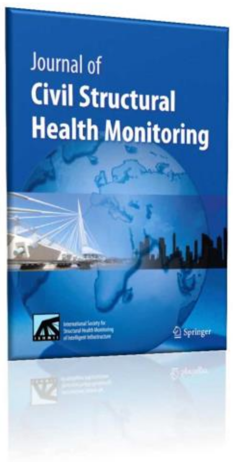
Rates Increase on January 4, 2013 to:

Individual $150
Corporate $500 (4 individuals)
Student $35 with status verification by your institution

For more information on membership, please visit ISHMII's Membership & Community page.

[Join for the first time or renew](#).

Members may access the Proceedings of CSHM-4 through the Knowledge & Education Center at ISHMII.org.



Journal of Civil Structural Health Monitoring

Volume 2, Number 2

(September 2012)

is now available to members on-line through ISHMII.org

Volume 3 will be available in January 2013

Sign-up for the Free *Table of Content Alert* Service from Springer

Just click on the Journal's homepage and enter your e-mail address in the box on the lower right side

Submissions for publication are accepted through

the *Journal's* Editorial Manager

CONFERENCES & WORKSHOPS

SHMII-6 Hong Kong December 9-11 2013

ISHMII invites you to attend the 6th International Conference on Structural Health Monitoring of Intelligent Infrastructure

FIRST CALL FOR PAPERS

SHMII-6 2013 is organized by the Department of Civil and Structural Engineering, The Hong Kong Polytechnic University.

CONTACT *THE MONITOR*

Sreenivas Alampalli, Editor-in-Chief Sreenivas.Alampalli@dot.ny.gov

Nancy Cohen, Managing Editor NancyC@ishmii.org

Associate Editors

Dr. Xin Feng Fengxin@dlut.edu.cn

Dr. Branko Glisic Bglisic@princeton.edu

Dr. Werner Lienhart Werner.lienhart@tugraz.at

Dr. Juan Antonio Quintana R. Jaquintana@imt.mx

Dr. Yong Xia Ceyxia@polyu.edu.hk

Details are available at

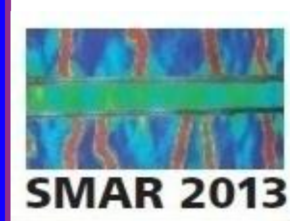
www.cee.polyu.edu.hk/shmii-6/home.html

MoDeRn

Monitoring Developments for Safe Repository Operation and Staged Clo

MoDeRn International Conference and Workshop, Luxembourg March 19-21, 2013

The MoDeRn Project announces the International Conference and Workshop - Monitoring in Geological Disposal of Radioactive Waste.



SMAR 2013 Istanbul, Turkey September 9-11, 2013

Second Conference on Smart Monitoring, Assessment and Rehabilitation of Civil Structures.

You can receive *The Monitor* twice a year and *Membership Notes*, a newsletter from ISHMII, for free.

Send your request to Managing Editor Nancy Cohen at NancyC@ishmii.org.

ISHMII

INTERNATIONAL SOCIETY FOR STRUCTURAL HEALTH MONITORING OF INTELLIGENT INFRASTRUCTURE

www.ishmii.org

Please Contact
ISHMII President
Dr. Farhad Ansari
at FAnsari@uic.edu

Farhad Ansari, Ph.D.
University of Illinois at Chicago
Civil & Materials Engineering (MC 246)
842 W. Taylor Street
Chicago, Illinois 60607-7023
USA

ISHMII Admin. Centre
University of Manitoba
Agricultural & Civil Engineering Bldg.
A250 - 96 Dafoe Road
Winnipeg, Manitoba
R3T 2N2
Canada