8th Civil Structural Health Monitoring Workshop (CSHM-8)

Ageing structures and infrastructures in hazardous environment

On-line, March 29-31, 2021

Program and Book of Abstracts

Organized by	Università degli Studi del Molise	ISHMII
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1. GENERAL INFORMATION

WORKSHOP ORGANIZATION

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2. WORKSHOP TOPICS

AGEING STRUCTURES AND INFRASTRUCTURES IN HAZARDOUS ENVIRONMENT

This Workshop represents a forum where experts from around the world discuss the latest advancements and breakthroughs in the field of civil structural health monitoring (SHM) and more broadly in the fields of smart materials and intelligent systems for civil engineering applications. The Workshop also fosters the discussion and identification of key and emerging challenges and opportunities in research, development, and field applications of SHM to civil structures and infrastructures. The CSHM-8 workshop is also intended to promote communication exchange and cross-fertilization among researchers and practitioners from all around the world sharing their expert knowledge in the field. The main theme of the Workshop is "Ageing structures and infrastructures in hazardous environment"; within the general theme of the Workshop, topics for CSHM-8 include:

- Geotechnical monitoring of civil infrastructure to extend life and improve safety;
- Addressing challenges in the practical application of structural health monitoring to civil infrastructure, with particular attention to bridges and historical structures;
- Innovative sensing technologies;
- Advanced data processing methods for civil SHM and SHM-based decision-making;
- Vibration-based structural assessment and monitoring, including SHM in earthquake prone regions.

3. INFORMATION FOR AUTHORS

PROGRAMME OVERVIEW

The Workshop is scheduled over three days, and it is organized in twelve sessions - single track -, that is to say, four sessions per day. Each Workshop day starts with a Keynote Lecture from a distinguished speaker in the field of civil SHM; after each Keynote Lecture, the sponsors will give a dedicated 5-min technical presentation before starting the Workshop sessions. The time zone is Central European Summer Time (CEST) (UTC+2:00).

	March 29th, 2021	March 30th, 2021	March 31st, 2021
8.30	**Opening ceremony**		
8.45	**Keynote Lecture 1** - Alvaro Cunha: *Dynamic Testing and Continuous Monitoring of Transportation and Energy Infrastructures* **Chair: C. Rainieri**	**Keynote Lecture 2** - Hong-Hu Zhu: *Fiber optic monitoring and forecasting of reservoir landslides* **Chair: G. Fabbrocino**	**Keynote Lecture 3** - Andrea Del Grosso: *Structural Health Monitoring for the management of existing structures: the UNI 11634 Guidelines* **Chair: G. Fabbrocino**
9.20	**5-min Technical Presentations from the Sponsors** **Chair: G. Fabbrocino**	**5-min Technical Presentations from the Sponsors** **Chair: N. Caterino**	**5-min Technical Presentations from the Sponsors** **Chair: F. Ceroni**
9.30 9.45 10.00 10.15 10.30	**Session #1: OMA and SHM (Special Session #1)** **Chair: C. Rainieri**	**Session #5: New sensing technologies and strategies for civil SHM (Special Session #3)** **Chair: L. Ierimonti**	**Session #9: SHM-based Decision making** **Chair: D. Losanno**
10.45	BREAK	BREAK	BREAK
11.00 11.15 11.30 11.45 12.00 12.15	**Session #2: OMA and SHM (Special Session #1)** **Chair: F. Ceroni**	**Session #6: New sensing technologies and strategies for civil SHM (Special Session #3)** **Chair: S. Taylor**	**Session #10: SHM in earthquake prone regions** **Chair: I. Nuzzo**
12.30	BREAK	BREAK	BREAK
14.00 14.15 14.30 14.45 15.00 15.15	**Session #3: Model Updating** **Chair: E. Reynders**	**Session #7: Geotechnics** **Chair: F. Santucci de Magistris**	**Session #11: Historical structures** **Chair: F. Ceroni**
15.30	BREAK	BREAK	BREAK
15.45 16.00 16.15 16.30 16.45	**Session #4: Bridge monitoring** **Chairs: C. Gentile**	**Session #8: Data Processing for SHM** **Chair: G. Fabbrocino**	**Session #12: SAR for civil SHM (Special Session #2)** **Chair: R. Ditommaso**
17.00 17.15			**Closing Ceremony and Announcement of the Best Paper Award**

The Workshop sessions include three Special Sessions:

SS1. **Operational Modal Analysis and Structural Health Monitoring (OMA-based SHM)** - *Chairs: Prof. M.L. Aenlle, Dr. C. Rainieri*

SS2. **Combined Structural Health Monitoring of existing structures and infrastructures using on-site and satellite acquisitions: the contribution of 2019-21 Reluis Project** – *Chairs: Prof. F.C. Ponzo, Prof. M. Savoia, Dr. R. Ditommaso*

SS3. **New sensing technologies and strategies for civil SHM** – *Chairs: Prof. F. Ubertini, Dr. C. Rainieri*

Each presentation is allocated 15 minutes in total, including 3 minutes for questions and discussion after each presentation; the session chair will notify the presenter when they have 2 minutes remaining before the end of presentation time. **Speakers must be strictly on time with their presentation**.

Presenting authors are kindly asked to prepare their slides in pdf format and upload them through their EasyChair account (following the instructions sent by email) **no later than March 27th, 2021** in order to have them regularly uploaded before the Workshop starts. The Workshop will be held on-line by using the EasyChair VCS platform.

Participants, Speakers and Chairs can practice the VCS platform through the links they will find in EasyChair under VCS → Information.

All sessions and talks will be recorded, so they can be accessed at a later time for attendees from different time zones.

All papers will be made available for download to all participants; the link to download the Workshop Proceedings, published in Lecture Notes in Civil Engineering and edited by Springer, will be sent to the participants after the Workshop.

4. TECHNICAL PROGRAM

	March 29th, 2021	March 30th, 2021	March 31st, 2021
8.30	**Opening ceremony**		
8.45	**Keynote Lecture 1** - Alvaro Cunha: *Dynamic Testing and Continuous Monitoring of Transportation and Energy Infrastructures*	**Keynote Lecture 2** - Hong-Hu Zhu: *Fiber optic monitoring and forecasting of reservoir landslides*	**Keynote Lecture 3** - Andrea Del Grosso: *Structural Health Monitoring for the management of existing structures: the UNI 11634 Guidelines*
9.20	**S2X SRL:** *S2X Products and Services for Civil SHM*	**NBG:** *Business Opportunities for SHM Based on Fiber Optic Sensing*	**SHM SYSTEM:** *Composite-DFOS Revolution*
9.25	**ITC-CNR:** *The GRISIS Italian research project*	**SMART TOWER SYSTEMS LLC:** *Smart Tower Systems Overview*	BREAK
	Session #1: SS1 OMA and SHM	**Session #5: SS3 New sensing technologies and strategies for civil SHM**	**Session #9: SHM-based Decision making**
9.30	**#41** Kohm et al. *Influence of Operational Conditions on the Modal Based Damage Analysis of Pedestrian Bridges*	**#86** Corvaglia et al. *Realization and testing of Textile Reinforced Concrete panels sensorized with distributed Fiber Optic Sensors*	**#9** Verzobio et al. *Consequences of heuristic distortions on SHM-based decision*
9.45	**#3** Wynne et al. *Mass and temperature changes in operational modal analysis*	**#69** Cascardi et al. *INNOVATIVE NON-DESTRUCTIVE TECHNIQUE FOR THE STRUCTURAL SURVEY OF HISTORICAL STRUCTURES*	**#87** Bouklas et al. *Increasing the Resilience of European Transport Infrastructure*
10.00	**#16** Santarsiero et al. *Out-of-plane ambient vibration tests and model validation of infill walls in RC frames subjected to previous in-plane damage*	**#46** D'Alessandro et al. *ADVANCED MONITORING OF STRUCTURES AND INFRASTRUCTURES THROUGH SMART COMPOSITE SENSORS AND SYSTEMS*	**#11** Pastorelli et al. *Estimation of Seismic Resilience of Road Infrastructures: an integrated approach*
10.15	**#91** Favarelli et al. *Data Management in Structural Health Monitoring*	**#35** Tonelli et al. *Acoustic emission monitoring of a prestressed concrete bridge tested to failure*	**#76** Caterino et al. *A technological platform for multi-risk monitoring, management and mitigation in Campania region, Italy*
10.30	**#2** Wynne et al. *Operational modal analysis of a historic GRP structure*	**#5** Kromanis *Characterizing footbridge response from cyclist crossings with computer vision-based monitoring*	**#77** Bilotta et al. *Feasibility analysis of artificial intelligence application to the structural monitoring of a metropolitan railway bridge*
10.45	BREAK	BREAK	BREAK
	Session #2: SS1 OMA and SHM	**Session #6: SS3 New sensing technologies and strategies for civil SHM**	**Session #10: SHM in earthquake prone regions**
11.00	**#101** Russotto et al. *OMA: from research to engineering applications*	**#108** Kumar et al. *Field evaluation of sensing sheet prototype exposed to cracking*	**#27** Salvatori et al. *Monitoring of base isolated building subjected to far fault earthquake*
11.15	**#6** Bernagozzi et al. *Damage detection through modal flexibility-based deflections: application to a full-scale RC shear wall building*	**#20** Polydorou et al. *Health monitoring of structures using integrated Unmanned Aerial Vehicles (UAVs)*	**#63** Arezzo et al. *Evolution of modal parameters of a reinforced concrete building subjected to moderate earthquakes*
11.30	**#71** Marcheggiani et al. *Experimental tests and numerical models on highway multi-span bridges: a case study*	**#57** Di Palma et al. *Two-dimensional deflection maps by using Fiber Bragg Grating sensors*	**#13** Lubrano Lobianco et al. *From signal to damage in a vibration-based analysis for long-term SHM*
11.45	**#72** Sbaraglia *Investigation in structural performances of high-power horizontal axis wind turbines by OMA-based SHM*	**#37** Di Giacinto et al. *Weight-in-Motion system for traffic overload detection: development and experimental testing*	**#110** Cakti et al. *Experimental Evidence for Structural Damage during the 30.10.2020 Sisam-Sigacik Earthquake by Laser Vibrometry*
12.00	**#19** Rizzo et al. *Data Processing Strategies for Monitoring an Offshore SPM system*	**#105** Biswas et al. *Numerical Evaluation of Corroded RC Columns Subjected to Reversed Cyclic Loading*	**#111** Spizzuoco et al. *STRUCTURAL MONITORING AND DYNAMIC CHARACTERIZATION OF THE MAIN FIRE STATION BUILDING IN NAPLES*
12.15	**#107** Nicoletti et al. *Expeditious Dynamic Tests for the Estimation of Infill Masonry Wall Stiffness*		**#114** Pollino et al. *Forecasting and managing natural hazard induced risks on critical infrastructures in Southern Italy: the RAFAEL project*
	BREAK	BREAK	BREAK
	Session #3: Model Updating	**Session #7: Geotechnics**	**Session #11: Historical structures**
14.00	**#98** Erduran et al. *Stange Overpass: Finite Element Model Updating of an unconventional railway bridge*	**#12** Nöther et al. *Distributed fiber-optic strain sensing: Field applications in tunnels, pile foundations and concrete beams*	**#39** Ierimonti et al. *Bayesian-based damage assessment of historical structures using vibration monitoring data*
14.15	**#89** Benedetti et al. *Multidisciplinary investigation of a steel-concrete composite bridge*	**#88** Sieńko et al. *Possibilities of composite distributed fibre optic 3DSensor on the example of footing pulled out from the ground: a case study*	**#81** Casapulla et al. *DYNAMIC BEHAVIOUR OF THE SANTA MARIA MADDALENA CHURCH IN THE ISCHIA ISLAND (ITALY): EXPERIMENTAL RESULTS AND*
14.30	**#59** Ponsi et al. *Bayesian model updating and parameter uncertainty analysis of a damaged fortress through dynamic experimental data*	**#92** Buchmayer et al. *Distributed fibre optic sensing for the long term monitoring of tunnel inner linings in an anhydrite area*	**#109** Cakti et al. *LONG TERM VIBRATION MONITORING OF THE SULTAN AHMET MOSQUE IN ISTANBUL*
14.45	**#94** Zonno et al. *Assessment of similar reinforced concrete arch bridges by operational modal analysis and model updating*	**#93** Schönberger et al. *Long-term monitoring using GNSS: Lessons learned and experiences from 20 years of operation*	**#97** Trizio et al. *Digital environment for remote visual inspection and condition assessment of architectural heritage*
15.00	**#60** Santoro et al. *Dynamic identification and model updating of a masonry chimney*	**#30** Santo et al. *Slope stability assessment of the test site in Pagani (Campania, Southern Italy)*	**#73** Marra et al. *Digital tools for the knowledge and safeguard of historical heritage*
15.15	**#28** Aloisio et al. *Non-parametric optimization using subspace-based objective functions*		**#17** De Angelis et al. *Assessment of an historical masonry bell tower by modal testing*
15.30	BREAK	BREAK	BREAK
	Session #4: Bridge monitoring	**Session #8: Data Processing for SHM**	**Session #12: SS2 SAR for civil SHM**
15.45	**#85** Desbazeille et al. *Monitoring of bridges by using static and dynamic data from MEMS accelerometers*	**#103** Kullaa *Time-Domain Damage Detection of Structures with Complex Modes under Variable Environmental Conditions Using Bayesian Virtual Sensors*	**#113** Fabbrocino et al. *A structural engineering perspective on the use of remote sensing measurements for civil SHM*
16.00	**#26** Reynders et al. *Vibration monitoring of a railway bridge using distributed macro-strain data obtained with fiber Bragg gratings*	**#40** Noori et al. *Comparative Study of Wavelet Parameter Selection for non-Parametric Analysis of Big Data in Structural Health Monitoring*	**#24** Budillon et al. *Infrastructure health monitoring using SAR Tomography*
16.15	**#33** Lydon et al. *Use of A Roving Vision Sensor Setup to Train an Autoencoder for Damage Detection of Bridge Structures*	**#15** Zhao et al. *Data-Driven nonparametric structural nonlinearity identification under known excitation with limited data fusion*	**#34** Ponzo et al. *An advanced approach to the long term SHM of structures and transport infrastructures*
16.30	**#10** Osmani et al. *Fatigue life prediction for a concrete - steel composite viaduct: a process based on indirect measurements*	**#56** Zeferino et al. *Monitoring system of an industrial steel tower structure*	**#78** Berto et al. *Assessment of the applicability of DInSAR techniques for structural monitoring of cultural heritage and archeological sites*
16.45	**#70** Losanno et al. *Structural monitoring of a railway bridge in southern Italy for real-time early warning strategy*	**#7** Obiechefu et al. *Damage detection techniques for vision-based deformation monitoring of horizontal structures*	**#106** Sartorelli et al. *Use of SAR satellite data in bridge monitoring with application to urban area*
17.00	**#25** Quintana et al. *Monitoring and Evaluation of a Highway Bridge during Major Rehabilitation*		**Closing Ceremony and Announcement of the Best Paper Award**
17.15			

5. KEYNOTE LECTURES: ABSTRACTS

KEYNOTE LECTURE #1 - MARCH 29TH, 2021

Dynamic Testing and Continuous Dynamic Monitoring of Transportation, Stadia and Energy Infrastructures

Speaker: *Prof. Álvaro Cunha*
CONSTRUCT-ViBest, Faculty of Engineering (FEUP), University of Porto, Portugal

Abstract. The Laboratory of Vibrations and Structural Monitoring (ViBest, www.fe.up.pt/vibest) of CONSTRUCT/FEUP has been implementing, since 2007, a significant set of long-term dynamic monitoring systems in large Civil structures with different typologies (e.g. roadway, railway and pedestrian bridges, stadia suspension roofs, wind turbines, concrete dams or high voltage transmission lines).
This paper briefly describes some of these applications, showing the interest and potential of the developed technology, as well as of the huge high quality database created, which can be used for joint collaborative research at European level.

Keywords: Continuous Dynamic Monitoring, Footbridges, Railway Bridges, Roadway Bridges, Stadia Suspension Roof, Wind Turbines, Concrete Dams.

KEYNOTE LECTURE #2 - MARCH 30TH, 2021

Fiber Optic Monitoring and Forecasting of Reservoir Landslides

Speaker: *Prof. Hong-Hu Zhu*
School of Earth Sciences and Engineering, Nanjing University, Nanjing, China

Abstract. Landslide hazards triggered by atmospheric precipitation and periodic water level fluctuations frequently occur in reservoir areas all over the world, resulting in severe fatalities and loss of properties. It is well known that the evolution and occurrence of reservoir landslides are subjected to multi-field interaction and combined triggering factors, such as he fluctuation of the water level, heavy rainfall and strong earthquakes. Thus there will be considerable errors if a landslide risk identification system solely depends on displacement measurements. For the purpose of detecting geological disasters ahead of time, a series of advance monitoring techniques have been developed and applied to engineering practices. Among them, the Distributed Fiber Optic Sensing (DFOS) technologies have shown their great potential for field monitoring a variety of geotechnical infrastructures such as tunnels and pile foundations. Their performance in monitoring the tempo-spatial distribution of multi-fields (temperature, seepage, stress, displacement, etc.) of reservoir landslides should be explored in details. On the other hand, a variety of data-driven models have been developed and employed for reservoir-induced landslide prediction, such as the updated grey model, logistic regression model, and the newly developed machine learning models. In this paper, the recent advancement in DFOS technologies for monitoring reservoir landslides is introduced, together with some innovative forecasting models. Their working principles, characteristics and applicability are briefly introduced. In particularly, several representative DFOS-based monitoring

instruments and equipment are elaborated, which have been successfully used in Majiagou landslide and Xinpu landslide in Three Gorges Reservoir (TGR) area in China for long-term observation and comprehensive evaluation of relevant geohazards. The monitoring results show that the sliding surfaces, deformation pattern, and groundwater evolution can be sensitively captured based on the DFOS measurements and the forecasting models. Seasonal rainfall and water level fluctuations are found to be the two main triggering factors of the two landslides. Finally, the challenges and future trends in this research area are summarized.

Keywords: Distributed Fiber Optic Sensing (DFOS), Field Monitoring, Reservoir Landslides, Three Gorges Reservoir (TGR).

KEYNOTE LECTURE #3 – MARCH 31ST, 2021

Structural Health Monitoring for the management of existing structures: the UNI 11634 Guidelines

Speaker: *Prof. Andrea Del Grosso*
University of Genova & RINA Consulting S.p.A., Genova, GE, Italy

Abstract. The Guidelines for Structural Health Monitoring have been released by UNI, The Italian Standard Organization, as Technical Report TR 11634 on April 2016, after a two- year work performed by a special purpose working group established by the Technical Committee CT 021 - Structural Engineering, mirror group of the European CEN TC 250 Committee. The scope of the Guidelines was to provide final users and system providers with a reference text for the conception, design, implementation, operation and maintenance of SHM systems in the country. The field of application of the Guidelines was intended to be limited to civil engineering structures, although most of the addressed concepts could be valid also for industrial applications. The working group was composed by experts from Italian Universities, system providers and structural designers, members of UNI.

As a difference from already existing guidelines published by different organization worldwide, the TR 11634 addresses the entire SHM process from the selection of the physical quantities to be measured, the selection of the measurement points in the structure, the selection of sensors, the desired accuracy of the measurement chain to the processing of the data provided by the system, the damage identification tools and, finally, to the usage of the information concerning the condition state of the structure in the management of the facility. The different approaches to structural health monitoring, either occasional, temporary or permanent are discussed in the Guidelines pointing out the respective use.

The presentation will review the main structure of the Guidelines recalling to evidence the main characteristics of the content, and the problems that still remained open to further developments. Actually, the Working Group is undertaking a revision of the standard UNI 10985, dedicated to the performance of dynamic measurements on bridges to include, besides the updating of the dynamic measurement techniques and of the dynamic data interpretation processes, the role that the knowledge of the dynamic responses may play in the development of SHM application on bridges.

Finally, the presentation will also briefly address the Guidelines for the classification and management of risks, safety evaluation and monitoring of existing bridges that have been released on April 2020 by the Italian Ministry of Infrastructure. These Guidelines recommend the installation of SHM systems on bridges classified in the highest categories of risk, making reference to the UNI 11634 Guidelines for the implementation and operation of SHM systems.

Keywords: UNI, Guidelines, Structural Health Monitoring, bridges.

6. ABSTRACTS

Paper index: [2], [3], [5], [6], [7], [9], [10], [11], [12], [13], [15], [16], [17], [19], [20], [24], [25], [26], [27], [28], [30], [33], [34], [35], [37], [39], [40], [41], [46], [56], [57], [59], [60], [63], [69], [70], [71], [72], [73], [76], [77], [78], [81], [85], [86], [87], [88], [89], [91], [92], [93], [94], [97], [98], [101], [103], [105], [106], [107], [108], [109], [110], [111], [113], [114]

[2] *Operational modal analysis of a historic GRP structure*

Zachariah Wynne (Institute for Infrastructure and Environment, University of Edinburgh)
Tim Stratford (Institute for Infrastructure and Environment, University of Edinburgh)
Thomas Reynolds (Institute for Infrastructure and Environment, University of Edinburgh)

Abstract. The Aberfeldy Footbridge was the world's first major advanced composite footbridge. Constructed from glass-fibre reinforced plastic (GFRP) in 1991, the lightweight cable-stayed footbridge provided the client with a low-cost access route which needed minimal site equipment for erection. Since opening to the public, the resin used within the structure has degraded exposing the glass fibres and there have been issues with the connections between various components of the bridge. Following damage to the structure in 1997 by the crossing of a light vehicle, the bridge deck was strengthened with bonded GFRP panels. It has been reported that there has been a gradual change in dynamic properties. Between 1995 and 2000 the damping of the first vertical mode is reported to have reduced by 52% with a reduction in natural frequency of 2%. Additional testing carried out in 2011 suggests that the natural frequency of the first vertical mode had reduced by a further 5%.

This paper presents a new analysis of data from previous dynamic tests carried out by other researchers in 2011 and 2013, alongside data from tests carried out by the authors in 2019. A variety of time and frequency domain operational modal analysis techniques are used to quantify the uncertainty within the results. The reported changes in dynamic properties over the past 14 years are compared to the known degradation and repair work carried out on the structure. These results indicate that the previously reported changes in dynamic properties may be due to weakly non-linear behaviour of the structure, close modes and non-damage induced changes in dynamic behaviour. This illuminates the information which can be gained from in-depth dynamic analysis of civil structures, the challenges of damage detection and the need to quantify the range of dynamic behaviour a structure may exhibit.

Time: March 29th, 10:30
Session: #1 – SS1: OMA and SHM
Keywords: Operational Modal Analysis, Historic Structures, Footbridge, Vibration Testing, Structural Health Monitoring, Glass Reinforced Plastic (GRP), Lightweight Structures, Non-linear behaviour

[3] *Mass and temperature changes in operational modal analysis*

Zachariah Wynne (Institute for Infrastructure and Environment, University of Edinburgh)
Georgios Kanellopoulos (Institute for Infrastructure and Environment, University of Edinburgh)
Vasileios Koutsomarkos (Institute for Infrastructure and Environment, University of Edinburgh)
Angus Law (Institute for Infrastructure and Environment, University of Edinburgh)
Tim Stratford (Institute for Infrastructure and Environment, University of Edinburgh)
Thomas Reynolds (Institute for Infrastructure and Environment, University of Edinburgh)

Abstract. A challenge in identifying the dynamic properties of large structures through operational modal analysis (OMA), whereby the response of a structure is measured under ambient excitation, are the changes in added mass and temperature which may occur during data collection. The effect of these changes may mask any damage to the structure or lead the investigator to incorrectly conclude damage has occurred. Quantification of such effects requires the use of short-time OMA methods, where the structure's response is assumed to be linear across short periods of time.

Two experiments were carried out to identify methods through which such variations can be accurately identified and quantified. The first experiment consisted of a simple I-beam with spring supports to which a small mass was added at a variety of locations to simulate changes in mass similar to that which may be induced by pedestrian or vehicle loading of civil structures. The changes in the dynamic properties were quantified through the short-time Fourier transform and a variant on the random decrement technique to test their ability to detect small changes in mass. An inversion of the mass change method is used to estimate both the quantity and location of the added mass.

The second experiment investigated the efficacy of the same short-time OMA methods in the presence of temperature variation. A flat plate was heated in laboratory conditions using radiant panels. The changes in dynamic properties were measured during heating, steady temperature and cooling of the plate, and the results correlated to the changes in temperature using variations on established relationships between elastic modulus and temperature.

The results presented within this paper provide an experimental basis for the viability of short-time OMA methods for quantifying temperature and added mass induced variation in dynamic parameters which may be used to guide future structural monitoring.

Time: March 29th, 09:45
Session: #1 – SS1: OMA and SHM
Keywords: Operational Modal Analysis, Mass change, Temperature change, Non-linear behaviour, Experimental analysis

[5] *Characterizing footbridge response from cyclist crossings with computer vision-based monitoring*

Roland Kromanis (University of Twente)

Abstract. Computer vision applications are frequently selected for short-term monitoring of bridges. The availability of high resolution and frame rate consumer-grade cameras such as action cameras makes the computer vision-based monitoring an attractive and affordable option. This paper presents findings from monitoring deformations of a steel girder footbridge subjected to cyclist loads captured with an action camera. A modified action camera with a zoom lens was located 35 m from the centre of the bridge. High resolution (720x1080 pixel) and high frame rate (240 fps) videos were recorded during cyclist crossings. Image processing, measurement denoising, vertical deflection interpretation and influence line (bridge signature) derivations are presented and discussed. Both static and dynamic responses are identifiable (discernible in vision measurements) and even tiny (a fraction of a millimetre) vertical deflections can be accurately computed from videos collected with the action camera.

Time: March 30th, 11:15
Session: #6 - SS3: New sensing technologies and strategies for civil SHM
Keywords: Computer vision-based monitoring, Deformation monitoring, Measurement preprocessing, Signal interpretation, Vertical deflections, Structural dynamics

[6] *Damage detection through modal flexibility-based deflections: application to a full-scale RC shear wall building*

Giacomo Bernagozzi (Department DICAM - University of Bologna)
Said Quqa (Department DICAM - University of Bologna)
Luca Landi (Department DICAM - University of Bologna)
Pier Paolo Diotallevi (Department DICAM - University of Bologna)

Abstract. In civil engineering structures it is highly desirable to detect the presence of damage and changes in the global structural behavior at the earliest possible stage, and, among the many existing strategies for vibration-based damage detection, modal flexibility (MF)-based approaches are promising tools. However, in most of the existing studies, the experimental validation of such approaches has been performed on small-scale laboratory structures, where damage has been artificially imposed as stiffness reductions, for example by substituting some structural elements. It is thus important to continue to test the effectiveness of such MF-based approaches on full-scale structures characterized by more realistic damaged conditions. This paper focuses on the methods for output-only damage detection and localization that are based on the estimation of structural deflections from modal flexibility, and the objective of this paper is to test the applicability of such methods for locating damage in a full-scale reinforced concrete (RC) structure that has experienced earthquake-induced damage. The considered structure is a shear wall building that can be modeled as a bending moment-deflecting cantilever structure, and was tested on the large-scale University of California, San Diego – Network for Earthquake Engineering Simulation (UCSD-NEES) shaking table. Two approaches, which are based, respectively, on the estimation of the curvature and the damage-induced rotation from the deflections, have been applied and compared on the data of the considered case study. These approaches have been applied in different scenarios characterized by different data sets and by a different number of degrees-of-freedom measured on the considered structure.

Time: March 29th, 11:15
Session: #2 - SS1: OMA and SHM
Keywords: Structural Health Monitoring, Damage Detection, Modal Flexibility, Shear Wall Building, Output-Only Modal Identification

[7] *Damage detection techniques for vision-based deformation monitoring of horizontal structures*

Chidiebere Brendan Obiechefu (Nottingham Trent University)
Rolands Kromanis (University of Twente)
Fouad Mohammad (Nottingham Trent University)

Abstract. Vision-based systems offer affordable, accurate, and rapid response measurements, which can support structural health monitoring of short to medium span bridges. This study investigates the feasibility of vision-based systems for condition assessment of beam structures by analysing the load-response mechanism. Damage detection and localization techniques from response (e.g., vertical deformation, curvatures, and tilts) induced by traffic loads are evaluated on a laboratory structure. The performance of damage detection techniques and potential limitations for vision-based measurement are firstly assessed on a numerical model, which is a replica of a laboratory structure (simply supported beam). The beam is built only after limitations are identified. The beam is subjected to moving load, which is simulated using a moving platform on wheels with adjustable mass and speed. Smartphones and action cameras are employed to capture beam response under loading. Damages are introduced by reducing the section area of the beam at three locations. Beam response is calculated using computer vision. Response is analyzed with the proposed damage detection and location techniques. A discussion is drawn on required camera resolution, measurement noise and drift, pixel motion accuracy, and damage severity. Recommendations and limitations are drawn for applications of vision-based damage detection techniques on full-scale structures.

Time: March 30th, 16:45
Session: #8 - Data Processing for SHM
Keywords: damage detection, vision-based deformation monitoring, condition assessment

[9] *Consequences of heuristic distortions on SHM-based decision*

Andrea Verzobio (University of Strathclyde)
Denise Bolognani (University of Trento)
John Quigley (University of Strathclyde)
Daniele Zonta (University of Trento)

Abstract. The main purpose of structural health monitoring (SHM) is to provide accurate and real-time information about the state of a structure, which can be used as objective inputs for decision-making regarding its management. However, SHM and decision-making occur at various stages. SHM assesses the state of a structure based on the acquisition and interpretation of data, which is usually provided by sensors. Conversely, decision-making helps us to identify the optimal management action to undertake. Generally, the research community recognizes people tend to use irrational methods for their interpretation of monitoring data, in-stead of rational algorithms such as Bayesian inference. People use heuristics as efficient rules to simplify complex problems and overcome the limits in rationality and computation of the human brain. Even though the results are typically satisfactory, they can differ from those derived from a rational process. Many heuristic behaviors have been studied and demonstrated, with applications in various fields such as psychology, cognitive science, economics and finance, but not yet in SHM-based decision. SHM-based decision-making is particularly susceptible to the representativeness heuristic, where simplified rules for updating probabilities can distort the decision maker's perception of risk. In this paper, we examine how representativeness affects the interpretation of data, providing a deeper understanding of the differences between a heuristic method affected by cognitive biases and the classical approach. Our study is conducted both theoretically through comparison with formal Bayesian methods as well as empirically through the application to a real-life case study about the evaluation of a bridge safety.

Time: March. 31st, 09:30
Session: #9 - SHM-based Decision making
Keywords: heuristics, representativeness, Bayesian inference, decision-making, reliability, bridge management

[10] *Fatigue life prediction for a concrete - steel composite viaduct: a process based on indirect measurements*

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Andrea Del Grosso (Rina Consulting S.p.a,Genova)
Paolo Basso (Rina Consulting S.p.a ,Genova)
Marcello Cademartori (Rina Consulting S.p.a ,Genova)
Federico Di Gennaro (AISCAT Servizi)
Fabrizio Federici (AISCAT Servizi)

Abstract. Traffic fatigue cycles generated in steel bridge components is one of the major issues that can affect these types of structures. This paper introduces a strategy aimed at the fatigue damage assessment and remaining fatigue life prediction of concrete – steel composite bridges under traffic loads using monitoring data. The novelty of the proposed approach consists in the possibility of performing the assessment by means of indirect measurements, i.e. predicting damage at structural sections different from sensors positions.

In the view of using BIM procedures to achieve this aim, a virtual model of the case study has been created. The identified position of the sensors and the selected fatigue hotspots of the bridge are implemented in the model. For the traffic simulation analyses, a Finite Element (FE) model has been derived from the previous Virtual Model. Multiple dynamic analyses (Direct Integration Time Histories) are then performed simulating pseudo-random realistic traffic flows over the bridge, which are used to train the machine learning process. For all the Monte Carlo simulations, the sensors strain and the hotspots cumulated damage are carried out. For the evaluation of the fatigue damage, the Palmgren – Miner rule is applied, while for the count of the stress cycles the Rainflow method is adopted.

The predictive model is finally created starting from the simulations, by interpreting the existing correlation between strain at sensors and damage at hotspots using a machine learning approach. Once ready, the predictive model can work with real monitoring data collected, providing information on the fatigue life of selected hotspots, thus contributing to plan lifetime maintenance. To support real-time lifecycle management of infrastructures, the acquired data and the corresponding fatigue predictions are visualized in the BIM model.

The strategy has been developed in the context of the European Project RAGTIME and has been applied on a real viaduct in the northern Italy, the Mondalavia viaduct.

Time: March 29th, 16:30
Session: #4 - Bridge monitoring
Keywords: BIM, Fatigue damage, Predictive Maintenance, SHM, Multiple Linear Regression, Machine Learning

[11] *Estimation of Seismic Resilience of Road Infrastructures: an integrated approach*

Daniele Pastorelli (Rina Consulting S.P.A.)
Andrea Del Grosso (Rina Consulting S.P.A.)
Marcello Cademartori (Rina Consulting S.P.A.)
Saimir Osmani (Rina Consulting S.P.A.)

Abstract. The asset management of road infrastructures in zones prone to seismic hazard requires the estimation of the seismic resilience of the network. This requires implications of both structural and transport engineering methods in order to correlate the possible damage of a given structure to the consequence on the entire network. The paper aims at developing a simplified, but still reliable method, for the estimation of the seismic resilience of a road network considering different structures and including a transport module.

First, the seismic vulnerability of the structures is defined by means of fragility curves developed with different methods depending on the level of knowledge of the structures. Second, the consequence of the structural damage on the road capacity has been estimated. The different scenarios of road capacity after the seismic event are then included in the traffic module in order to estimate the post earthquake response of the road network.

Time: March 31st, 10:00
Session: #9 - SHM-based Decision making
Keywords: seismic vulnerability, seismic resilience, road infrastructures, infrastructures management, infrastructures maintenance

[12] *Distributed fiber-optic strain sensing: Field applications in tunnels, pile foundations and concrete beams*

Nils Nöther (fibrisTerre Systems GmbH)
Massimo Facchini (fibrisTerre Systems GmbH)

Abstract. This paper gives an overview over industrial applications of distributed fiber-optic strain sensing in structural health monitoring, outlining both the benefits of the technology and its challenges regarding installation of the fiber-optic sensing cables and limitations of the measurement technology itself.

With a focus on the Brillouin Optical Frequency Domain Analysis and Reflectometry (BOFDA/R) as the specific technology for distributed strain sensing in optical fibers, we discuss the nature of distributed sensing data and its characteristic performance parameters such as spatial resolution, strain accuracy, temperature cross-sensitivity, measurement speed and optical attenuation budget.

These theoretical considerations are illustrated with a number of use cases from field assignments of the technology in tunnelling, static load tests of pile foundations, and load measurements in pre-stressed concrete beams.

Time: March 30th, 14:00
Session: #7 - Geotechnics
Keywords: fiber-optic sensing, Brillouin sensing, BOFDA, BOTDA, BOFDR, BOTDR, strain sensing, distributed sensing

[13] *From signal to damage in a vibration-based analysis for long-term SHM*

Alessandro Lubrano Lobianco (University of Naples “Federico II”)
Marta Del Zoppo (University of Naples "Federico II")
Marco Di Ludovico (University of Naples "Federico II")

Abstract. One of the main issues in civil engineering is to estimate the level of damage for existing buildings subject both to decay due to natural aging and to additional loads that could affect their serviceability during lifetime. This paper looks at the process of long-term Structural Health Monitoring (SHM) in the con-text of damage detection and quantification. The aim of the paper is to define ranges of variation for parameters commonly monitored as structural damage indicators, like fundamental periods, residual drift ratios and lateral stiffness, in relation with seismic damage levels. For this purpose, a methodology is proposed for simulating the seismic damage of existing reinforced concrete (RC) columns and assessing the correlation between the variation of such parameters with in-creasing damage levels. Seismic damage levels are defined based on the Park and Ang damage index, and preliminary ranges of variation of damage indicators are derived for the seismic damage quantification in existing RC columns.

Time: March 31st, 11:30
Session: #10 - SHM in earthquake prone regions
Keywords: structural health monitoring, damage quantification, period elongation, stiffness degradation

[15] *Data-Driven nonparametric structural nonlinearity identification under known excitation with limited data fusion*

Ye Zhao (Huaqiao University)
Bin Xu (Huaqiao University)
Baichuan Deng (Hunan University)
Jia He (Hunan University)

Abstract. Nonlinear restoring force (NRF) identification for a structural member under dynamic loading provides more valuable information for damage prognosis (DP) because NRF provides a direct description of damage initiation and development procedure and can be employed to determine energy dissipation quantitatively during the vibration. However, it is challenging to model the real nonlinear behavior of a structure member or a substructure in a parametric way in prior because of the individuality of structural nonlinearities associated with different construction materials and structural systems. In this paper, a data-driven NRF identification approach in a nonparametric way for multi-degree-of-freedom (MDOF) structures under unknown input measurements using limited fused dynamic response measurements is proposed, where a double Chebyshev polynomial combined with an updated Extended Kalman filter (U-EKF) approach is employed. The proposed approach is validated numerically with MDOF structures equipped with various nonlinear members including MR damper (damping-dominant) and SMA damper (stiffness-dominant) employed to mimic different structural nonlinear behavior. Experimental study on a four-story steel frame model equipped with MR damper is carried out to validate the proposed method. Results show that the proposed approach is capable of identifying the damper forces provided by different dampers and unknown excitation in a nonparametric way, which is very helpful for post-event condition evaluation of engineering structures where structural nonlinearity should be considered but input is usually unknown.

Time: March 31st, 12:15
Session: #10 - SHM in earthquake prone regions
Keywords: nonlinear restoring force, updated Extended Kalman Filter (U-EKF), double Chebyshev polynomial model, SMA dampers, MR dampers, nonparametric identification

[16] *Out-of-plane ambient vibration tests and model validation of infill walls in RC frames subjected to previous in-plane damage*

Giuseppe Santarsiero (University of Basilicata)
Alessandra De Angelis (University of Sannio)
Vincenzo Manfredi (University of Basilicata)
Francesco Santamato (University of Sannio)
Angelo Masi (University of Basilicata)
Maria Rosaria Pecce (University of Sannio)

Abstract. Masonry infill walls are widely used as enclosure elements in reinforced concrete (RC) buildings to provide thermal and acoustic insulation. Past earthquakes have identified the out-of-plane collapse of the masonry infill walls as one of the predominant modes of failure. Out-of-plane failure is characterized by brittle behaviour and it is therefore a threat to human safety. Moreover, the out-of-plane capacity may be significantly affected by the presence of cracks due to the in-plane damage related to the interstorey drift. In order to identify the out-of-plane behaviour of infill walls depending on the in-plane damage, an experimental campaign based on cyclic quasi static tests has been initiated on a full-scale infilled RC portal frame at the Laboratory of Structures of the University of Basilicata. The one-bay (4.5m span), one story (3m height) frame infilled with two layers of hollow clay brick walls 8cm and 12cm thick, has been subjected to in-plane loading by means of three reversed cycles for each increasing amplitude, until the story drift was equal to 2% and extensive damage occurred to both the infills and the RC members. After each set of tree in-plane cycles, a dynamic identification of the infills' layers has been carried out based on ambient vibrations in order to detect changes in its dynamic behaviour. This latter, using sixteen accelerometers placed on the infills' surface. The identification tests provided valuable information regarding the out-of-plane (OOP) frequencies, vibration modes and damping during the test as function of the in-plane drift. The paper describes the results of the ambient vibration tests and the validation of a finite element model.

Time: March 29th, 10:00
Session: #1 - SS1: OMA and SHM
Keywords: Infill walls, masonry, out-of-plane, in-plane damage, model validation

[17] *Assessment of an historical masonry bell tower by modal testing*

Alessandra De Angelis (University of Sannio)
Francesco Santamato (University of Sannio)
Maria Rosaria Pecce (University of Sannio)

Abstract. Masonry heritage structures are among the most vulnerable typologies during earthquake. Their safety assessment requires a higher degree of accuracy due to the lack of knowledge on the original design and the construction procedures. The collection of information about the hidden geometry and the material properties should be performed by non-destructive techniques to avoid any damage to the artistic value. Moreover, for the assessment of the structural behavior of the tower a reliable method is the structural identification by on-site dynamic test.

In this paper the results of the behavior ambient vibration test and operational modal analysis are reported to calibrate a FE model of the historical masonry bell-tower of S. Sofia. The bell tower of S. Sofia is part of the monumental complex of S. Sofia, in Benevento together with the S. Sofia church, the monastery and the fountain. In 2011, this monumental complex was added in the World Heritage List of UNESCO. The bell tower is about 27 meters high and it is characterized by a shaft which extends for a height of about 12 m, it has the shape of a hollow parallelepiped with a square base. The belfry is characterized by regular and equal openings on all four faces and it is surmounted by an octagonal lantern with a dome with eight segments.

The calibrated model of the tower is used for the verification of the structure under vertical loads and seismic actions, because the location is an area of high-medium hazard.

Time: March 31st, 15:15
Session: #11 - Historical structures
Keywords: bell-tower, masonry, modal testing, updated model, seismic assessment

[19] *Data Processing Strategies for Monitoring an Offshore SPM system*

Michele Rizzo (DICeA University of Florence)
Ostilio Spadaccini (DICeA University of Florence)
Paolo Castelli (Edison E&P SpA Siracusa)

Abstract. Near the offshore production platform Vega A, the tanker FSO Leonis is moored to a steel column with circular section, 130 meters high and 10 meters in diameter, installed in 1988 in the Sicilian Channel, the connection is via a bridge structure (yoke) with welded steel sections that make up the system SPM (Single Point Mooring). The structural system in steel box girders and column, with its cylindrical hinges, is calls-to the actions of the sea that induce cyclic stresses and fatigue. The document presents the improvement strategies of the monitoring system of the structure that connects the ship to the column, originally installed in October 2009. The original monitoring system is composed of strain gauges sensors, in fiber optic, and inclinometers biaxial that detect rotations of the column and the bridge. New gyro on the tanker FSO and optical thermal sensors on yoke are installed, and a new control unit will allow, together with the inclination data, to verify the ship's pull on the column. The new control unit will have a high acquisition frequency that will allow us to investigate the structural modes shape of the system and yoke. The results allowed us to evaluate the conditions assumed in the project and made it possible to define a program of inspection and maintenance of steel structures.

Time: March 29th, 12:00
Session: #2 - SS1: OMA and SHM
Keywords: Single Point Mooring (SPM), Dynamic Response, Dynamic Identification

[20] *Health monitoring of structures using integrated Unmanned Aerial Vehicles (UAVs)*

Efstathios Polydorou (Queen's University)
Desmond Robinson (Queen's University)
Su Taylor (Queen's University)
Patrick McGetrick (NUI Galway)

Abstract. Unmanned aerial vehicles (UAVs), known as drones, is an advanced remote sensing technology gaining much interest in the field of civil engineering in the last few years. According to the Association of Unmanned Vehicle Systems International, it is estimated that drones have the potential of reaching an economic benefit of US $82 billion by 2025. This paper investigates novel strategies for the visual inspection assessment and damage detection of bridge condition by maximizing the full potential of UAVs remote technology combined with advanced camera vision methods. The investigation starts by assessing the functionality of modern UAVs and matching the capabilities to the requirements of bridge monitoring. This is important as the driving force behind the technology development of drones has not come from bridge maintenance, but it is important that we exploit the new technologies and the same argument is also true for image processing. The paper explores how these assessment techniques can be transferred on to a UAV platform. The paper not only looks at the important technical issues such as camera stabilization both from flight control and image processing but also the use of UAVs as an inspection and measuring device. The investigation makes use of both laboratory experiments and field trials to assess the effectiveness of the proposed schemes.

Time: March 30th, 11:30
Session: #6 - SS3: New sensing technologies and strategies for civil SHM
Keywords: Unmanned Aerial Vehicles, Structural health monitoring, Bridge Engineering, Dynamic displacements, Computer vision

[24] *Infrastructure health monitoring using SAR Tomography*

Alessandra Budillon (University of Naples Parthenope)
Giampaolo Ferraioli (University of Naples Parthenope)
Angel Johnsy (University of Naples Parthenope)
Vito Pascazio (University of Naples Parthenope)
Gilda Schirinzi (University of Naples Parthenope)

Abstract. Static structures, such as bridges and dams, are in need of continuous structural health monitoring due to the risk of collapse or destabilization, which leads to casualties and material loss. From economical point of view, the frequent inspection of these structures is cost-ineffective and time consuming. This shortage is overcome by using remote sensing systems such as synthetic aperture radar (SAR) systems, that work in all metrological conditions and observe the Earth on a very large spatial scale and at regular time intervals.

Tomographic Synthetic Aperture Radar (TomoSAR) [1] is a multi-dimensional imaging technique that exploits stacks of interferometric images acquired with slightly different view angles and at different times to obtain the full 3D reflectivity profile of the ground scene. TomoSAR is also able to analyze the temporal deformations and Earth movements on buildings and concrete structures. The small movements that occur due to thermal sensitivity of the structure are also captured. The widespread deterioration and some recent collapses of infrastructures have highlighted the im-portance of developing early warning monitoring strategies, devoted to identify structural problems before they become critical. A problem to be considered is that, since structural subsidence typically takes place in a small area depending on the size of the structure, effective monitoring techniques have to rely on approaches capable of identifying few representative points, which describe well the dynamical behavior of the structure. A TomoSAR technique recently developed, based on a multi-step binary hypothesis GLRT test [2,3], has shown a good capability of selecting reliable control points on the structure for estimating its deformations. In order to demonstrate the potentialities of this technique for structure health monitoring, two structures will be considered, a bridge and a building. The results obtained using different SAR sensors, such as Cosmo-SkyMed, Sentinel-1 and TerraSAR-X, will be presented.

[1] G. Fornaro, V. Pascazio, “SAR Interferometry and Tomography: Theory and Applications”, Academic Press Library in Signal Processing, Communications and Radar Signal Processing, Vol. 2, Cap. 20, pp. 1043-1117, Elsevier Ltd. 2013.

[2] A. Budillon, A. Johnsy, G. Schirinzi. “A Fast support detector for superresolution localization of multiple scatterers in SAR tomography”. IEEE J. Selected Topics Applied Earth Obs. Remote Sens., 10(6), pp. 2768-2779, 2017.

[3] A. Budillon, A. Johnsy, G. Schirinzi. “Extension of a fast GLRT algorithm to 5D SAR tomography of Urban areas”, Remote Sensing, 9(8), 844, pp.1-21, 2017.

Time: March 31st, 16:00
Session: #12 - SS2: SAR for civil SHM
Keywords: Infrastructure health monitoring, Remote sensing, Synthetic aperture radar, Tomography

[25] *Monitoring and Evaluation of a Highway Bridge during Major Rehabilitation*

Juan Quintana (Instituto Mexicano del Transporte)
Francisco Carrión (Instituto Mexicano del Transporte)
Miguel Anaya (Instituto Mexicano del Transporte)
Germán Guzmán (Universidad Autónoma de Sinaloa)
Jorge Hernández (Instituto Mexicano del Transporte)
Luis Martinez (Instituto Mexicano del Transporte)
Héctor Gasca (Instituto Mexicano del Transporte)
José Machorro (Instituto Mexicano del Transporte)

Abstract. After a severe accident, El Carrizo Bridge reported extensive damage and was closed to traffic. This bridge is on the Mazatlán-Durango highway, which is an important route for tourism and commerce in the northwest region of Mexico; for that reason, it was a priority to open traffic and reduce the economic impact estimated at more than USD 250,000 per day. To address the emergency and recover the traffic on the highway, even partially, the authorities proposed a two-stage rehabilitation strategy; the first stage, to build two provisional lanes to allow traffic under restricted conditions and, the second, to rehabilitate the bridge with the provisional lanes in operation. The previous strategy put forward several safety challenges and required the installation of a SHM system with a permanent evaluation to assure structural and operational conditions. This work describes the way that specialists designed the monitoring system and the evaluation strategy, based on the conditions of the rehabilitation works and processes.

Time: March 29th, 17:00
Session: #4 - Bridge monitoring
Keywords: Structural Health Monitoring, Bridge Rehabilitation, Structural Evaluation

[26] *Vibration monitoring of a railway bridge using distributed macro-strain data obtained with fiber Bragg gratings*

Edwin Reynders (KU Leuven)
Dimitrios Anastasopoulos (KU Leuven)
Guido De Roeck (KU Leuven)

Abstract. Recent advances in optical sensing and signal processing technologies have resulted in strain sensing systems that can accurately capture the very small dynamic strain levels occurring in civil structures during ambient excitation. In particular, it has been demonstrated in a laboratory environment that the combination of fiber Bragg grating (FBG) sensors with an acquisition system that interrogates those sensors with a swept monochromatic signal, can accurately capture RMS strain values with an order of magnitude of 0.01 microstrain. In the present work, the potential of this novel sensing technology for civil structural health monitoring is explored for a steel bow-string railway bridge that has been monitored for over one year. Both sides of the bridge deck have been instrumented with chains of multiplexed FBG sensors that are fixed to the bridge in discrete points. In this way, dynamic macro-strains are measured in a continuous way along the entire length of the bridge. During the monitoring period, the bridge underwent a retrofitting operation, in which all connections between the hangers and the bridge's deck and bow were altered. The influence of this retrofit on the monitored eigenfrequencies and strain mode shapes is investigated and compared with their regular environmental variation.

Time: March 29th, 16:00
Session: #4 - Bridge monitoring
Keywords: Submission for special Session #3: New sensing technologies and strategies for civil SHM, Keywords:, fiber-optic strain sensing, operational modal analysis, bridge engineering

[27] *Monitoring of base isolated building subjected to far fault earthquake*

Antonello Salvatori (University of L'Aquila)
Antonio Di Cicco (University of L'Aquila)
Paolo Clemente (ENEA, Casaccia Research Center)

Abstract. The seismic monitoring of buildings is important for two fundamental reasons:

- evaluate the possible dynamic behavior of these structures during earthquakes;

- gain experience on the general seismic behavior of the structures to permit the use of a database for future design and analysis.

The results of previous work in seismic monitoring of the structures permitted the development of a database, which in turn was used in the creation of new formulas and reference values for the estimation of the fundamental periods of the structures and to evaluate the percentage of critical damping from use during dynamic analyzes.

The database is very well supplied with data on traditional buildings, but there is still not enough data for buildings with base isolation.

Some different structures with seismic base isolation have been monitored during recent strong earthquakes in Italy, namely Amatrice earthquake (2016/08/24, Mw=6.0) and Norcia earthquake (2016/10/30, Mw=6.5).

For the structure under examination, in far fault condition, amplification phenomena have been noticed, up to about twice the accelerations on the superstructure, for very low energy value inputs. In these cases, however, it is noticed that the amplified accelerations are extremely small, and very far from being able to damage the structure.

Records from the ENEA permanent accelerometric network, installed in the structure under examination, and the tests carried out on the same isolators used for the qualification test of the devices below the analyzed structure, permit to describe the behavior of the isolators in terms of force and displacement defining two non-linear laws, derived from experimental data.

The non linear analysis of the building behaviour using the referred experimental laws evidenced the good fitting between experimental data and numerical simulation, while linear analyses evidenced some significant differences.

Time: March 31st, 11:00
Session: #10 - SHM in earthquake prone regions
Keywords: Seismic engineering, Seismic isolation, Far fault earthquakes, Dynamic in situ monitoring

[28] *Non-parametric optimization using subspace-based objective functions*

Angelo Aloisio (Università degli Studi dell'Aquila)
Riccardo Cirella (Università degli Studi dell'Aquila)
Rocco Alaggio (Università degli Studi dell'Aquila)
Massimo Fragiacomo (Università degli Studi dell'Aquila)

Abstract. The tuning of structural models to the experimental dynamic response entails the choice of a proper objective function. The goal of the so-called model updating process is the optimization of the chosen objective function, which measures the discrepancy between the experimental and simulated dynamic responses. This research focuses on the application of a non-parametric subspace-based objective function to the estimation of the modelling parameters of a beam-like structure. Differently from parametric optimization, non-parametric objective functions do not require the assessment of the modal parameters and descend from direct manipulation of the experimental and simulated data. The use of parametric optimization may lead to the discard of important information, which could be lost when extracting the modal parameters. Conversely, non-parametric optimization may store valuable information, which may lead to the estimation of both the stiffness and mass matrices even in the case of operational response, characterized by unknown excitation.

In a second step, the research focuses on the quantification of the uncertainty of the estimand parameters following an elementary Bayesian approach.

The authors attempt to estimate the probability density function of the parameters by isolating and quantifying two sources of uncertainties: the uncertainty of the structural model and that of the optimization method.

Time: March 29th, 15:15
Session: #3 - Model Updating
Keywords: Operational Modal Analysis, Uncertainty quantification, Discrete optimization, Finite Element model.

[30] *Slope stability assessment of the test site in Pagani (Campania, Southern Italy)*

Antonio Santo (Dipartimento d'Ingegneria Civile, Edile e Ambientale; Università di Napoli Federico II) Marianna Pirone (Dipartimento d'Ingegneria Civile, Edile e Ambientale; Università di Napoli Federico II) Giovanni Forte (Dipartimento d'Ingegneria Civile, Edile e Ambientale; Università di Napoli Federico II) Melania De Falco (Dipartimento d'Ingegneria Civile, Edile e Ambientale; Università di Napoli Federico II) Gianfranco Urciuoli (Dip. d'Ingegneria Civile, Edile e Ambientale; Università di Napoli Federico II)

Abstract. Flowslides are rainfall-induced events initiating with the shear failure at a depth of few meters or less, which downslope increase in volume for avalanche effect and velocity. Unfortunately, Campania Region (Southern Italy) has been historically affected by such events. They represent a relevant hazard for the structures and the infrastructures located at foothills. Predisposing conditions for flowslide initiation are related to the current values of soil water content and matric suction into the subsoil. Those parameters, if correctly monitored, can represent a valuable tool for the definition of early warning strategies against these phenomena. This paper reports preliminary results on the test site set up in Pagani (SA). Its position is strategical, as it is upslope of the highway from Naples to Salerno in an area affected by historical events respectively occurred in 1960, 1972 and1997; the latter reached the highway and killed two people. Topographic survey of the area has been performed with a UAV, while stratigraphic and geotechnical characterization in both field and laboratory were carried out. Here the stratigraphic setting of the site and the preliminary geotechnical soil properties are re-ported. Finally, soil stability has been assessed through the infinite slope model; here, the variation in the safety factor (SF) as a function of the slope angle and of different suction scenarios is shown. These results permit to identify the most critical conditions and the most dangerous areas, where flowslide triggering could occur and, thus, affecting the highway downslope.

Time: March 30th, 15:00
Session: #7 - Geotechnics
Keywords: Flowslides, Unsaturated soil, Slope stability, Campania Region

[33] *Use of A Roving Vision Sensor Setup to Train an Autoencoder for Damage Detection of Bridge Structures*

Darragh Lydon (Queens University Belfast)
Su Taylor (Queens University Belfast)
Juliana Early (Queens University Belfast)
Myra Lydon (Queens University Belfast)

Abstract. This paper will demonstrate a solution for detecting damage to a bridge structure from measured displacements gathered using a roving vision sensor based approach. The measurement of displacement was accomplished using a synchronised multi-camera contactless vision based multiple point displacement measurement system using wireless action cameras. Displacement measurements can provide a valuable insight into the structural condition and service behaviour of bridges under live loading. Computer Vision systems have been validated as a means of displacement calculation, the research developed here is intended to form the basis of a real time damage detection system. This is done through the use of unsupervised deep learning methods for anomaly detection which could form the basis of a low cost durable alternative which is rapidly deployable in the field. The performance of the system was evaluated in a series of controlled laboratory tests. This research provides a means of detecting changes to a bridge structure through use of minimal sensor installation, reducing potential sources of error and allowing for potential live rating of bridge structures.

Time: March 29th, 16:15
Session: #4 - Bridge monitoring
Keywords: Computer Vision, Structural Health Monitoring, Anomaly Detection, Deep Learning

[34] *An advanced approach to the long term SHM of structures and transport infrastructures*

Felice Carlo Ponzo (School of Engineering, University of Basilicata)
Chiara Iacovino (School of Engineering, University of Basilicata)
Rocco Ditommaso (School of Engineering, University of Basilicata)
Gianluca Auletta (School of Engineering, University of Basilicata)
Francesco Soldovieri (Institute for Electromagnetic Sensing of the Environment (IREA), National Council of Research (CNR))
Manuela Bonano (Institute for Electromagnetic Sensing of the Environment (IREA), National Council of Research (CNR))
Vincenzo Cuomo (Institute of Methodologies for Environmental Analysis (IMAA), National Council of Research (CNR))

Abstract. This work shows the preliminary monitoring results by applying in situ and re-mote sensing systems to a school building located in Ariccia (Rome), within the WP6 "Structural Health Monitoring and Satellite Data" 2019-21 Reluis Project.

In particular, the use of the remote sensing Differential Interferometry Synthetic Aperture Radar (DInSAR) has provided a spatial map of the displacement of the investigated structure and the corresponding time-series with the aim of monitoring deformation phenomena, focusing on the local scale analysis, which produces suitable results for urban monitoring and damage assessment. The DInSAR results have been integrated with the identification of the dynamic characteristics of the structure. In-situ data was provided by the Seismic Observatory of Structures (OSS), a network of permanent seismic monitoring systems managed by the Italian Department of Civil Protection (DPC). Modal parameters were identified from the accelerometric responses recorded at several floors of the buildings.

The integrated use of the two techniques has allowed to confirm the healthiness of the investigated structure, even in presence of several seismic events occurred in the area during the monitoring period. This case represents a good example about how the integration of in-situ sensors with remotely sensed data is a key factor for a sustainable structural and infrastructural monitoring and can support the planning of both maintenance and safety management.

Time: March 31st, 16:15
Session: #12 - SS2: SAR for civil SHM
Keywords: Remote Sensing, Synthetic Aperture Radar, Interferometry, Structural Health Monitoring, Transport Infrastructures

[35] *Acoustic emission monitoring of prestressed concrete bridges: differences before and after the first-crack opening*

Daniel Tonelli (University of Trento)
Francesco Rossi (University of Strathclyde)
Michele Luchetta (University of Trento)
Daniele Zonta (University of Trento)
Placido Migliorino (Ministero delle Infrastrutture e dei Trasporti)
Alberto Selleri (Autostrade per l'Italia SpA)
Enrico Valeri (Autostrade per l'Italia SpA)
Alessandra Marchiondelli (Autostrade per l'Italia SpA)
Gianluca Ascari (Akron srl)

Abstract. A great amount of highway bridges is reaching the lifespan for which they were designed, and most of them need frequent inspections and maintenance to guarantee the safety of users. Structural health monitoring can help infra-structure operators to estimate promptly and accurately the structures' health condition. The progress of technology has encouraged the development of modern non-destructive monitoring techniques, such as the acoustic emission (AE) method. Recent experiences testify its potential, especially applied to the detection of cracks' initiation and propagation in structures where it is difficult to perform visual inspection or direct measurements. In this paper, we analyze and correlate the results of AE techniques with the initiation and propagation of damage in a full-size prestressed concrete high-way bridge subjected to a load test up to its failure: the Alveo Vecchio Via-duct. The bridge, built in 1968 and regularly maintained over the years, is representative by type, age, and deterioration state of similar bridges in operation on the Italian highway network. We aim to identify the differences in AE recorded on a real-life structure before and after the first-crack opening, and more in general, the effectiveness of AE techniques in permanent or short-term monitoring.

Time: March 30th, 10:15
Session: #5 - SS3: New sensing technologies and strategies for civil SHM
Keywords: acoustic emission, damage detection, crack initiation, crack propagation, prestressed concrete bridge, load test, structural health monitoring

[37] *Weight-in-Motion system for traffic overload detection: development and experimental testing*

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Giovanni Laudante (SMA Road Safety)
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Abstract. A new load cell-based Weight-in-Motion (WIM) equipment for detecting traffic overload conditions on the roadway structure is proposed. The system consists of two load detection sensors, a supporting and stiffening steel structure, a reinforced concrete (RC) basement, and a steel covering plate. Embedded within the road pavement at grade with the top asphalt surface, the sensors are offset to avoid missing values while gathering the data from the passing vehicle. This strategy ensures the passage of both the axle's wheels through the measuring area, which is the top surface of a steel beam support-ed by four load cells. Being the beam width smaller than the wheel's contact surface, a tailored algorithm has been implemented to process the gathered data and return the Gross Vehicle Weight (GVW). More than 500 experimental tests have been performed to assess the system's performance. A relatively rigid basement reduces the noise related to the vibrations generated by the system itself, which might affect the data analysis. Nonlinear dynamical FE analyses have been performed to support the structural design. A reduction in operating costs is allowed by the streamlined low-maintenance con-figuration of the system, along with its robustness.

Time: March 30th, 12:00
Session: #6 - SS3: New sensing technologies and strategies for civil SHM
Keywords: weight-in-motion, data analysis, traffic overload detection

[39] *Bayesian-based damage assessment of historical structures using vibration monitoring data*

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Enrique García-Macías (University of Perugia)
Ilaria Venanzi (University of Perugia)
Filippo Ubertini (University of Perugia)

Abstract. The high level of damage suffered by historical structures due to the interaction between materials' aging and seismic events that occurred during the last decade has revealed the need for developing reliable and long-lasting prevention techniques. In this context, long-term structural health monitoring (SHM) is a practice that has been spreading in recent years. A monitoring system is composed by an optimized network of sensors placed in strategic positions within the building. The data recorded by the sensors enable to track the structural behavior over time.

In this study an automated Bayesian-based procedure, i.e., an inverse problem able to detect in real-time the occurrence of damage, is proposed. In particular, hourly data are periodically divided into subgroups and used for the automatic Bayesian update. The methodology can be summarized as follows: i) preliminary calibration of a Finite Element (FE) model able to reproduce the structural dynamic behavior identified by the experimental vibration data; ii) identification of damage-sensitive portions of the structure by performing non-linear static analyses (NLSA) on the FE model; iii) calibration of a digital twin of the structure by surrogate modeling and definition of the sensitivity damage chart; iv) real time Bayesian model updating of the selected uncertain parameters in order to continuously identify possible changes in the structural behavior that can be associated with a certain level of damage.

Time: March 31st, 14:00
Session: #11 – Historical structures
Keywords: Bayesian approach, Damage detection, Structural Health Monitoring, Architectural heritage

[40] *Comparative Study of Wavelet Parameter Selection for non-Parametric Analysis of Big Data in Structural Health Monitoring*

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Ahmed Silik (Southeast University)
Wael Altabey (Alexandria University)

Abstract. A critical issue facing structural health monitoring is how to analyze the massive amounts of non-stationary sensor data (NSD) and how to best correlate the information to important structural characteristics. Wavelet transform (WT) is an effective tool for analyzing NSD. However, the challenge to ensuring the WT effectiveness in analyzing NSD is the appropriate wavelet selection for data decomposition, data denoising and feature extraction. Using various wavelets, with varied characteristics to analyze the same data may lead to varied results due to different properties of each wavelet type. Thus, the question that which wavelet is best suited for the analysis of NSD, has remained open and no well-developed guidelines have been reported in the literature in this regard. Moreover, no rule has been introduced to define the superiority of one base function over another. Vast majority of WT techniques are based on individual measure, linear correlation or energy and often not suited for the detection of incipient defects. This study proposes a new detailed framework for selecting a proper wavelet that can be customized for NSD and for separating disturbances and extracting damage features. Our method considers data type, its characteristics, application purposes, wavelet properties, band characteristics, similarity and sharing information measurements, and reconstruction quality. The novelty of this study lies in integrating multi-measures such as linear correlation index, Mean square error, signal to noise and energy/entropy ratio, and new proposed measures such as nonlinear correlation, information quality ratio, energy moment, retained energy and others to evaluate various base wavelets capabilities in proper decomposition of structural dynamic responses. The accuracy of the technique is evaluated using simulated and excremental data. The results show that db3 and sym3 exhibit a better performance in terms of all quantitative parameters compared to others. This strategy can be applied to applications beyond civil engineering.

Time: March 30th, 16:00
Session: #8 - Data Processing for SHM
Keywords: Wavelet, mother wavelet, quantitative measures, non-stationary signal

[41] *Influence of Operational Conditions on the Modal Based Damage Analysis of Pedestrian Bridges*

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Lothar Stempniewski (Karlsruhe Institute of Technology)

Abstract. Modal based monitoring systems for civil engineering structures, especially for bridge constructions, receive more attention in recent years. The goal of those systems is to detect damage processes at an early stage. This enables quick reaction to damages and ultimately extends the life of existing bridges while also minimizing maintenance costs. The modal parameters, namely natural frequencies and mode shapes are dependent on the stiffness and mass distribution of the structure. Since the traffic loads represent temporally and spatially variable stiffness and mass distributions of the bridge structure, the question arises how reliably the modal parameters can be estimated, and if structural stiffness changes can be distinguished from the variable stiffness and mass distributions of traffic load.

In this paper, the influence of pedestrian traffic on the estimation of the modal parameters is investigated. Spring-Mass-Damper systems represent the pedestrians to be able to take human mass, damping and stiffness effects into account. The vertical acceleration responses are considered for single pedestrians and a crowd of pedestrians using probabilistic approaches. The influence of the operating loads is first numerically investigated using an Euler-Bernoulli beam model and then compared with the results of vibration measurements on a pedestrian bridge. We can substantiate, that pedestrian volume, the ratio of the natural frequencies of the bridge superstructure to the step frequency of the pedestrians as well as the measurement length are the decisive criteria for successful damage identification. A clear distinction between the amplitude scatter of the mode shapes due to traffic loads and a structural stiffness change is possible by appropriate selection of the damage identification methods. The contribution of this paper consists in the investigation of the influence of operational loads on the estimated mode shapes and the establishment of the relationship to the modal based damage analysis.

Time: March 29th, 09:30
Session: #1 - SS1: OMA and SHM
Keywords: modal-based bridge monitoring, operating conditions, pedestrian bridge

[46] *ADVANCED MONITORING OF STRUCTURES AND INFRASTRUCTURES THROUGH SMART COMPOSITE SENSORS AND SYSTEMS*

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Hasan Borke Birgin (University of Perugia - Department of Civil and Environmental Engineering)
Filippo Ubertini (University of Perugia - Department of Civil and Environmental Engineering)

Abstract. The monitoring of the behavioral conditions of structures and infrastructures during their service life and after critical events is an extremely timely topic. The potentialities of novel sensors and systems stay in their reliability and flexibility. Indeed, due to their peculiar characteristics which could possess localized features, structures should be instrumented by diffuse sensing systems. Traditional sensors could generally be placed only in a limited number of locations by external applications: these occurrences weaken their durability and reliability. Boosted performance are coming from novel smart mate-rials which can combine structural performance with enhanced properties, as sensing ones. In particular, the authors have made several research efforts on the preparation and the application of self-sensing structural materials, cement- and clay-based, doped with conductive fillers. This paper presents the investigation of sensing capabilities and the possible applications of cementitious materials with different carbon-based fillers. Such composites could be embedded or can constitute structural elements, thus generating a diffused smart monitoring system. Possible applications stay in the monitoring of all kinds of concrete structures and infrastructures, including dynamic monitoring, traffic monitoring, damage detection, analysis of the strain/stress field variations.

Time: March 30th, 10:00
Session: #5 - SS3: New sensing technologies and strategies for civil SHM
Keywords: Smart sensors and systems, carbon-based fillers, cementitious materials, structural health monitoring, static and dynamic monitoring

[56] *Monitoring system of an industrial steel tower structure*

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Paulo Carapito (VESAM Engenharia S.A.)
Filipe Santos (VESAM Engenharia S.A.)

Abstract. Structural Health Monitoring (SHM) systems of civil engineering structures aim to assess and ensure the safety of the structures and the public. An SHM should detect possible damages as well as their locations and severity. Economic benefits are also expected if a predictive model can successfully forecast the remaining service life and the need for maintenance interventions. This paper describes a real-world application of an SHM system on an industrial steel tower structure. This is a high steel structure, containing several machines that support different loads and operate at different frequencies. The monitoring approach includes a numeric modeling of the structure, primarily used to define the sensor network. The sensors were mounted at anticipated locations designed to continuously measure the vibrations and deformations at critical points. The sensor network consists of an array of sensors and a gateway. The sensors include strain gauges and triaxial accelerometers, as well as temperature, humidity and other weather sensors. Data are acquired both from time series of values observed at regular intervals and from structurally relevant measured values, called events, where specific data are collected. Machine learning is used in the development of statistical models for feature discrimination. A visualization user interface is provided to access all data through a user friendly and accessible tool. The paper presents the main results obtained so far, including the structure modes of vibration, and the primary assessment of the structural health conditions.

Time: March 30th, 16:30
Session: #8 - Data Processing for SHM
Keywords: SHM, Sensor network, Machine Learning, Real world application

[57] *Two-dimensional deflection maps by using Fiber Bragg Grating sensors*

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Massimo Della Pietra (University of Naples “Federico II” and I.N.F.N. Naples)
Vincenzo Canale (University of Naples “Federico II” and I.N.F.N. Naples)
Mariagrazia Alviggi (University of Naples “Federico II” and I.N.F.N. Naples)
Agostino Iadicicco (University of Naples "Parthenope")
Stefania Campopiano (University of Naples "Parthenope")

Abstract. In this work, a novel technique to estimate the deflection of a bi-dimensional structure by means of fiber Bragg gratings (FBGs) is proposed. FBGs are embedded in monitored structure, avoiding the complex wiring typical of strain gauges, and provide local strain measurements. Then, by classical beam theory, from the strain maps measured by the FBGs, the two-dimensional deflection map of the monitored structure is numerically provided. The proposed method allows to overcome the difficulties existing in the direct measurement of the deflection: many types of structures (small and large) can be monitored in real-time thanks to this technique by using appropriate design parameters. In particular, this method can be useful in the structural monitoring of civil infrastructures and composite materials for aeronautics.

The method starts by calculating the polynomial function of the strain on different lines of the monitored structure by least mean square analysis. Then, the coefficients of the deflection polynomial are estimated by means of simple arithmetic operations on the coefficients of the strain polynomial. Finally, the three-dimensional profile of the deflection on the whole structure is calculated by means of polynomial fitting with two variables.

The proposed technique has been tested in a rectangular multilayer panel 100 cm long, 40 cm width and 0.95 cm thick formed by aluminium honeycomb bonded between two epoxy glass layers. This panel has been sensorized with 13 commercial FBGs 10 mm long distributed along three straight lines on a side, one on the other side useful for the neutral axis estimation and another strain free for the thermal compensation.

The structure has been subjected to bending load and the results obtained with this procedure compared with those provided by direct deflection measurements given by a mechanical comparator.

Experimental results show good agreement between the deflection indirectly measured by the FBGs and directly measured by the mechanical comparator, and a resolution of few tens of microns was reached in this test.

Time: March 30th, 11:45
Session: #6 - SS3: New sensing technologies and strategies for civil SHM
Keywords: Deflection monitoring, Fiber Bragg grating, Optical fibers

[59] *Bayesian model updating and parameter uncertainty analysis of a damaged fortress through dynamic experimental data*

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Loris Vincenzi (DIEF - University of Modena and Reggio Emilia)

Abstract. Vibration-based structural monitoring methods have been widely used in recent years for the evaluation of the dynamic performance and damage assessment of a wide scenario of civil structures. They represent powerful tools in the civil engineering field because they are able to provide real-time information on the structural health state during the structural life or after a catastrophic event (e.g. earthquake, hurricane). For this aim, it is evident that the numerical procedure used to obtain the possible damage state must be reliable and efficient in time-demand. Finite Element (FE) model updating techniques based on ambient or forced vibrations are tools able to localize a damage identified as a change in the structural stiffness starting from the vibration response measurements. The assessment of uncertainty of the identified parameters is of significant relevance especially for damaged structures and when the decision-maker has to decide to close a bridge or a building to prevent any effect of a possible collapse of the structure. This paper describes the results of the modal updating of an historical masonry fortress damaged by the seismic event that hit the town of San Felice sul Panaro and the surrounding localities in the Po Valley in the 2012. A standard updating procedure and a Bayesian procedure are first applied to calibrate the complex FE model of the fortress with respect to experimental modal data. The uncertainty of the identified parameters of structural systems is then evaluated by using the Bayesian probabilistic approach. The most probable parameter vector is obtained by maximizing the posterior probability density function. The robustness and the efficiency of the procedure are assessed through the comparison with the results obtained from the estimation of the Pareto-optimal solutions.

Time: March 29th, 14:30
Session: #3 - Model Updating
Keywords: model updating, masonry, damaged fortress

[60] *Dynamic identification and model updating of a masonry chimney*

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Loris Vincenzi (DIEF - University of Modena and Reggio Emilia)

Abstract. Vibration-based structural monitoring method is a widely used tools for the evaluation of the dynamic performance or for the damage assessment of historical towers and chimney. These structures are generally tall and slender and they tend to be sensitive to dynamic load as wind and earthquake because of their size and flexibility. Moreover, these kinds of structures can be highly vulnerable to the effects of dynamic actions of wind and earthquakes. To evaluate the structural safety, the load-structure dynamic interaction must be taken into account. The paper presents the results of dynamic tests performed on a historical masonry chimney. The studied masonry chimney exhibits a moderate but extensive crack pattern; for this reason, an extensive non-destructive test campaign is performed. The paper describes the dynamic test and the measurements of the structural response in operational conditions, the identification of the structural modal properties, the calibration of a structural Finite Element model based on the experimental results and the evaluation of the effect of cracks on its dynamic behavior.

Time: March 29th, 15:00
Session: #3 - Model Updating
Keywords: dynamic test, model updating, masonry chimney

[63] *Evolution of modal parameters of a reinforced concrete building subjected to moderate earthquakes*

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Sandro Carbonari (DICEA Università Politecnica delle Marche)
Fabrizio Gara (DICEA Università Politecnica delle Marche)

Abstract. In this work the results of the dynamic monitoring carried out on a school building located in Camerino (Italy) during the seismic sequence following the main shock of 2016 Central Italy earthquake are presented. The building, located in the historical centre of the town, consists of a reinforced concrete frame structure with masonry infill walls. The school was built in the 1960s and was seismically retrofitted in 2013 through the construction of 2 dissipative towers that is a recent patented system for the seismic protection of constructions. The system consists on steel truss towers built outside the building, pinned at their base and equipped with dissipative devices that activate for the rocking of the tower that are then rigidly coupled with the structure at its floor levels. In August 2016 a dynamic monitoring system was installed on the building, positioning the accelerometers both on the last two floors of the structure and on the foundation level; this allowed the recording of the building response to the aftershocks that occurred during the monitoring period, and the corresponding seismic input. Therefore, it has been possible to follow the evolution of the dynamic characteristics of the building during the seismic swarm, keeping track of the modal parameters of the structure identified through input-output techniques (N4SID) in occurrence of seismic events, and through consolidated output-only techniques (SSI) in the periods between two subsequent events.

Time: March 31st, 11:15
Session: #10 - SHM in earthquake prone regions
Keywords: Aftershocks, operational modal analysis, experimental modal analysis, dynamic identification, seismic dynamic monitoring

[69] *Innovative non-destructive technique for the structural survey of historical structures*

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Francesco Micelli (Università del Salento, Lecce)
Maria Antonietta Aiello (Università del Salento, Lecce)

Abstract. Masonry heritage buildings are typically vulnerable under seismic forces, due to the original design based on gravity load and, at the same time, the long-term decay effects. Nowadays, the computation of the vulnerability index is crucial for seismic evaluation and conservation strategies. An accurate geometric survey is a key-step for the learning process, especially in geometry-governed structural elements (e.g. in vaults, members with variable cross-section, etc.). In the case of huge building, scaffolding is commonly assessed in order to touch the structure for measuring or sensors installing (e.g. laser scanner). Minor damages are accepted when scaffoldings are fixed to the structure even in case of cultural Heritage.

In the present study an innovative drone-based technique for geometric survey is proposed, it is aimed to be fully non-destructive. A drone is equipped with a high-resolution camera (3D rotating) and GPS-system for the spatial positioning. By reaching a sufficient number of photos, the whole surface of the building can be covered. The database is then processed in order to compute a points cloud. Consequently, the points are linked and the wireframe model is reached. Finally, surfaces are generated in between the edges and the meshed model is made. The procedure is intended to be reproduced over the time for monitoring potential crack or local instability.

In order to demonstrate the validity of the proposal, a pilot building was selected. It is a masonry church with a large dome on the top (about 15 m diameter) and the variable thickness of the walls (about 50%). The indoor and outdoor photos were acquired by drone. Finally, the solid model was met by means of a specific designed Grasshopper-based code. In addition, the solid model was imported in a finite elements habitat, ready for the structural analysis.

Time: March 30th, 09:45
Session: #5 - SS3: New sensing technologies and strategies for civil SHM
Keywords: Masonry, Heritage, Seismic, Survey, Drone, Monitoring

[70] *Structural monitoring of a railway bridge in Southern Italy for automatic warning strategy*

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Nicola Caterino (University of Naples Parthenope)
Eugenio Chioccarelli (Università degli Studi Mediterranea di Reggio Calabria)
Carlo Rainieri (Construction Technologies Institute, Secondary Branch of Naples, National Research Council of Italy (CNR))
Carolina Aiello (Construction Technologies Institute, Secondary Branch of Naples, National Research Council of Italy (CNR))

Abstract. In the last few years, a growing interest towards structural safety of existing infrastructures has been paid. Due to very large number of structures, the scientific community is asked to provide innovative solutions that are both sustainable and reliable from the economical as well as technical point of view.

This paper presents the case of Quarto bridge, selected as case study in an Italian research project for Risks and Safety Management of Infrastructures at Regional Scale (GRISIS). The structure is a railway viaduct on an urban train line, located in the Northern metropolitan area of Naples. It consists of 45 simply-supported prestressed girders sustained by reinforced concrete piers, for a total length of approximately one kilometer. According to the project, the viaduct was equipped with an on-site monitoring system for near-real-time mitigation of seismic risk. The system involves some innovative, low-cost, sensors developed and installed to be tested on the field. This paper describes the monitoring system and the implemented strategies for risk mitigation referring to a single beam-column system but its application can be potentially replicated and implemented for large scale mitigation strategies.

Time: March 29th, 16:45
Session: #4 - Bridge monitoring
Keywords: GRISIS project, FEM Model, Innovative Sensors, Monitoring System, Seismic Alarm, Early Warning

[71] *Dynamic identification and monitoring of a new highway bridge*

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Francesco Clementi (Polytechnic University of Marche)
Antonio Formisano (University of Naples Federico II)

Abstract. The structural behaviour of viaducts under traffic or seismic excitations can be evaluated using Structural Health Monitoring (SHM) methods, which can also be usefully employed to evaluate their health state under service conditions. These methods allow the calibration of suitable FEM models, based on accurate information on both material properties and structural elements, which are used to both design and evaluate the effectiveness of consolidation interventions, if needed. In the paper, static and dynamic testing procedures applied to a multi-span bridge, called Adda viaduct, along a new high-way link inaugurated in 2014 in Northern Italy, are inspected. The structural performances of the investigated viaduct are evaluated on the basis of both experimental static and dynamic loading test results. In particular, Operational and Experimental Modal Analyses are used and their results are compared to each other. From the comparison it is shown that the dynamic load test can complement the static load one for the structural evaluation of new viaducts and can also be taken as an alternative for the monitoring of operational viaducts.

Time: March 29th, 11:30
Session: #2 - SS1: OMA and SHM
Keywords: Structural health monitoring, Bridges, Dynamic testing, Operational modal analysis, Experimental modal analysis

[72] *Investigation in structural performances of high-power horizontal axis wind turbines by OMA-based SHM*

Luca Sbaraglia (Rina Consulting SpA)

Abstract. A monitoring campaign of the tower mast vibrations of four identical high-power Horizontal Axis Wind Turbine Generator was conducted by Rina Consulting SpA. The scope of the work is to find the raisons of different performances between the investigated wind turbines. The monitoring was conducted by using real time chains of seismic accelerometers and the data analysis was completed by the OMA, operational modal analysis technique. The results made it possible to highlight the differences in dynamic behaviour between the investigated WTs. Starting from OMA results and using the design characteristics of the turbines, a set of dynamic indicators like unitary mass normalized modal shapes, flexibility matrix and modal shape curvature and was calculated. The differences in the calculated indicators made it possible to provide an explanation of differences in WT performances and to suggest a series of interventions to mitigate the consequences of the sub-optimal performances.

Time: March 29th, 11:45
Session: #2 - SS1: OMA and SHM
Keywords: Operational Modal Analysis, Wind Turbine, Scaled Mode Shape, Flexibility Matrix, Mode Shape Curvature, Short Time Fourier Transform

[73] *Digital tools for the knowledge and safeguard of historical heritage*

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Ilaria Trizio (Institute for Construction Technologies, Italian National Research Council - L'Aquila)
Giovanni Fabbrocino (Department of Biosciences and Territory - University of Molise)

Abstract. In last years, the Italian historical heritage revealed its high fragility due to relevant events caused both by natural phenomena and by lack of maintenance. The suffered damages highlighted the need to act to prevent and/or control degradation and mitigate the effects of endogenous and external hazards. The increased need of safeguarding the historical heritage and the advances in digital technologies applied to cultural heritage pushed towards novel conservation and risk mitigation procedures, such as proactive conservation plans. These plans may take advantage of novel digital tools for the survey, diagnosis, conservation and monitoring associated to a digital twin of the construction and of its relevant structural and non-structural components. These tools are able to manage and deploy a digital knowledge of the buildings conditions, both conservative and structural, and thus drive maintenance and restoration process with the aim of increasing the resilience of historical heritage.

In the paper, a prototypal digital model of historical architectural and artistic assets is illustrated in order to discuss the maturity of the approach and the aspects still open. The testing covers both structural and artistic components from a conservation and seismic viewpoint. A cost-benefit analysis is pro-posed in order to point out perspectives of the novel technologies and the opportunities of integration between static data coming from the geometry, history (construction sequences and technology) and dynamic data resulting from monitoring systems envisaged as an additional support to operators having in charge the conservation and safety of historical constructions.

Time: March 31st, 15:00
Session: #11 - Historical structures
Keywords: Historical Heritage, Digital Tools, Architectural survey, Conservation, Structural Monitoring

[76] *A technological platform for multi-risk management and mitigation in Campania region, Italy*

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Marilena Esposito (STRESS S.c.ar.l.)
Antonio Novellino (ETT S.p.A.)
Iolanda Nuzzo (Institute of Technologies for Construction, Italian National Research Council (CNR))
Antonio Occhiuzzi (Institute of Technologies for Construction, Italian National Research Council (CNR))
Ennio Rubino (STRESS S.c.ar.l.)

Abstract. Urban areas and relative built heritage may be exposed to different types of risk, according to their specific features. Safety management of civil infrastructures should be oriented towards a multidisciplinary approach to achieve a holistic analysis of risks (both natural and human made). In this perspective, the GRISIS research project (Risks and Safety Management of Infrastructures at Regional Scale) aims at developing a multi-risk technological platform for Campania region, in South Italy. It allows to gather and store different types of data concerning the area of interest, thus providing essential information in order to conceive methods and tools for management and mitigation of multiple risks to infrastructures and building networks.

This paper focuses on the proposal of methods and tools for the management and mitigation of seismic risk on infrastructures and building networks, developed within GRISIS project framework. Tolerable seismic risk levels for an existing building are a balance between the reduction of risk and the cost of rehabilitation. This study attempts to develop a decision-making procedure to figure out how to distribute the available budget in order to get the maximum possible portfolio risk reduction, identifying how to intervene on each single building. The proposed seismic risk mitigation strategy is uploaded in the GRISIS multi-risk technological platform, creating an interactive user-friendly tool, available online, that provides the best economic resources allocation after selecting the available budget for a specific portfolio of buildings.

Time: March 31st, 10:15
Session: #9 - SHM-based Decision making
Keywords: Risk management, Multi-risk analysis, Regional scale risk

[77] *Machine learning approach for damage detection of railway bridges: preliminary application*

Antonio Bilotta (Di.St. Dept - University of Naples Federico II)
Christian Capuano (Di.St. Dept - University of Naples Federico II)
Giusiana Testa (Di.St. Dept - University of Naples Federico II)
Eugenio Chioccarelli (Dept of Civil, Energy, Environmental and Materials Engineering - Mediterranea University of Reggio Calabria)

Abstract. In the framework of structural health monitoring, a 'model-free' approach has been gaining increasing attention to describe the structural behavior without building a numerical model but adopting the so-called artificial neural networks (ANNs) that must be trained on data (e.g., accelerations) record-ed on the existing structure. However, the lack of complete 'real-life' applications is the biggest current shortcoming to the use of ANNs. Indeed, the application of ANNs is often limited to medium-scale structures. The few applications on full scale structures are rarely run for a time interval sufficient to recognize structural deterioration due to material degradation and/or damage due to external loads. Moreover, the formulation of a methodology to design the sensor network serving a neural network is necessary.

In the context of a regional research project for Risks and Safety Management of Infrastructures at Regional Scale (GRISIS), ANNs are used by authors to develop a methodology for damage detection of railway bridges where the repetitive load condition, due to the passage of trains, is particular-ly favorable to the purpose. The potential damage detection is investigated referring to the structural accelerations recorded at a limited number of points of the structure. At this stage of the project, recorded data are not yet available, so an auxiliary numerical model of the structure is considered.

Time: March 31st, 10:30
Session: #9 - SHM-based Decision making
Keywords: data driven methods, bridge maintenance, machine learning, artificial neural networks

[78] *Assessment of the applicability of DInSAR techniques for structural monitoring of cultural heritage and archeological sites*

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Andrea Doria (Università IUAV di Venezia)
Anna Saetta (Università IUAV di Venezia)
Alberto Stella (Università IUAV di Venezia)
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Abstract. Structural health monitoring (SHM) practices have become increasingly important in the field of vulnerability assessment and risk mitigation of cultural heritage, especially after the past strong seismic events. Monitoring practice of monumental buildings and archeological sites could be really expensive using traditional on-site techniques. In the recent years, many steps towards have been taken in the developments of the Differential Interferometric Syn-thetic Aperture Radar (DInSAR) technique, which allows to monitor huge areas both in situations of ordinary maintenance and post-emergency conditions. The aim of this work is to analyze the applicability of recent DInSAR techniques for the structural monitoring of buildings belonging to cultural heritage and archeological sites. After a literature review highlighting the most relevant applications in this field, two case studies from the built cultural heritage are examined, in order to evaluate the reliability and the major issues occurring in the applicability and of DInSAR data for monitoring their health status. COSMO-SkyMed data relative to the urban area of Rome in the period 2011 – 2019 are used for the analyses. The small baseline subset (SBAS) processing technique was employed to obtain interferometric dis-placement measures.

Time: March 31st, 16:30
Session: #12 - SS2: SAR for civil SHM
Keywords: Archeological sites, Heritage buildings, Remote sensing, DInSAR

[81] *On the dynamic performance of the Santa Maria Maddalena Church, Ischia Island (Italy): numerical and experimental comparative analysis*

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Thomas Celano (University of Naples "Parthenope")
Francesca Ceroni (University of Naples "Parthenope")
Carlo Rainieri (National Research Council of Italy)
Giovanni Fabbrocino (University of Molise)

Abstract. After the seismic event of August 21st, 2017 that hit the Ischia Island (Italy), in-situ surveys were carried out on several masonry churches located in the island in order to assess the damage induced by the earthquake. Among the inspected churches, a very interesting case study is represented by the Santa Maria Maddalena Church, located on the hill of Casamicciola Terme, close to the epicentre. The church was built in 1896 with a 'mixed' structure, made of yellow tuff masonry walls strengthened by iron profiles in its main body and by wooden elements in its back part.

After the seismic event, in addition to a detailed survey of the church, thermography imaging and in-situ dynamic tests under operational conditions were carried out. The paper describes the experimental procedures adopted during the tests and the results in terms of experimentally identified fundamental modal parameters. An attempt of correlating the experimental results with those obtained from a finite element numerical model of the only church façade is carried out. The comparison evidences some discrepancies between the dynamic features of the single façade and the whole church. This confirms that the church is characterized by a 'box behaviour', most likely favoured by the presence of the iron frames, and, thus, the behaviour of the single façade cannot be considered independent of that of the whole church.

Time: March 31st, 11:15
Session: #11 - Historical structures
Keywords: Church, Masonry, Dynamic tests, FEM validation, Seismic response

[85] *Monitoring of bridges by using static and dynamic data from MEMS accelerometers*

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Nathalie Saguin Sprynski (CEA Grenoble)
Viviane Cattin (CEA Grenoble)
Malvina Billères (CEA Grenoble)
Laurent Jouanet (CEA Grenoble)
Audrey Vidal (CEA Grenoble)

Abstract. Structural Health Monitoring methods may be divided into two major categories depending on the type of data used during the damage identification: static or dynamic. In this paper, it is shown that both analyses can be performed with the same instrumentation composed only of Micro Electro Mechanical System (MEMS) accelerometers. The latter has the capability to measure static and dynamic data. In very low frequency, accelerometers are used as inclination sensors to estimate static deflection. In higher frequency, accelerometers are used as vibration sensors to perform modal analysis. Both analyses are illustrated in the case of a real footbridge. Static deflections and modal flexibility-based deflections are compared in operational conditions, including pedestrian loads and temperature changes, and in artificially-introduced damage conditions. Very good agreements are obtained showing the relevance of the two approaches. Static and dynamic analyses could be used in a complementary way and provide additional information in order to reinforce the confidence and the accuracy of the damage identification.

Time: March 29th, 15:45
Session: #4 - Bridge monitoring
Keywords: Structural Health Monitoring, damage identification, static and dynamic data, deflection, modal flexibility matrix, modal flexibility-based deflection

[86] *Realization and testing of Textile Reinforced Concrete panels sensorized with distributed Fiber Optic Sensors*

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Michael Brancato (Rina Consulting S.p.A.)
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Abstract. The paper presents the realization and testing of Textile Reinforced Concrete (TRC) panels sensorized with distributed Fiber Optic Sensors (FOS).

Proper procedures for fastening the sensor to the textile before its insertion as panel reinforcement, as well as for protecting the sensor during and after concrete casting were investigated.

Two samples were then realized, one reinforced with traditional steel mesh, one reinforced with sensorized textile mesh. FOS and reference electrical strain gages were applied to both.

The panels were tested in flexure up to failure, in order to investigate the effect of mesh substitution and of strain monitoring by means of the embedded distributed FOS, interrogated with Brillouin technique.

The paper discusses the obtained results, which confirm the feasibility of the pro-posed set-up, though evidencing the need of few enhancements to the sensor embedding technique.

Time: March 30th, 09:30
Session: #5 - SS3: New sensing technologies and strategies for civil SHM
Keywords: Textile Reinforced Concrete, Fiber Optic Sensors, monitoring

[87] *Increasing the Resilience of European Transport Infrastructure*

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Visvanathan Ramesh (GUF)
Guillermo Heredia (USE)
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Abstract. Extreme weather conditions, climate change, damages to the infrastructure (caused by natural and man-made hazards) and traffic impediments negatively impact the reliability of mobility solutions. Risk analysis, adaptation measures and strategies that enable minimizing the impact of both natural and man-made extreme events on seamless transport operation, protect the users of the transport network in case of extreme conditions, as well as provide optimal information to operators and users of the transport infrastructure, need to be developed.

Road transport is the most vulnerable mode to extreme weather events, while bridges and tunnels are among the most critical land transport structures. A large number of bridges and tunnels have been in operation for more than half a century and there are widespread signs of deterioration. They need inspection, vulnerability assessment and, when needed, appropriate interventions. Inspection, though, in inaccessible bridge and tunnel areas, or structures with high volumes of traffic, is expensive, time-consuming, and potentially dangerous. At the same time, structural/vulnerability assessment is also a lengthy process which is especially painful after extreme events.

The overall goal of RESIST is to increase the resilience of seamless transport operation to natural and man-made extreme events, protect the users of the European transport infrastructure and provide optimal information to the operators and users of the transport infrastructure. In the context of RESIST, robotics for visual and contact inspection of structures, structural vulnerability assessment, infrastructure risk management as well as mobility continuity applications considering stress levels of the drivers are being developed towards a high level of resilience of the transport infrastructure. The RESIST technology will be deployed and validated in 2 pilots in real conditions and infrastructures.

Time: March 31st, 09:45
Session: #9 - SHM-based Decision making
Keywords: Resilience, Transport, Infrastructure, Extreme Conditions

[88] *Possibilities of composite distributed fibre optic 3DSensor on the example of footing pulled out from the ground: a case study*

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Łukasz Bednarski (AGH University of Science and Technology in Cracow)
Tomasz Howiacki (Cracow University of Technology)
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Sławomir Labocha (University of Technology in Katowice)

Abstract. Distributed fibre optic sensing (DFOS) provides breakthrough possibilities in the field of structural health monitoring (SHM) in comparison to convention-al spot measurements. It allows the measurements to be registered over entire measuring length, not only in one point of the structure. That is why it is be-coming more and more attractive for geotechnics and civil engineering applications, providing both technical and economic benefits. However, to utilize all advantages of distributed sensing it is necessary to apply appropriate sensors, which will be able to accurately reflect the real structural behaviour. The paper discusses in situ application of unique (patented) composite DFOS displacements sensors (3DSensors), which were embedded into the ground layers compacted around the footing. The research was conducted to observe the potential slip plane generated during the pulling the footing out of the ground. Distributed measurements enabled to obtain the vertical displacement profiles around the footing within the selected ground layers with a spatial resolution of 1cm. Finally, special visualization of ground deformation in 3D space was performed to analyze in detail the cooperation be-tween the footing and the surrounding ground. No other techniques were able to obtain such information, as their presence inside the ground layers would disturb its behaviour. The operational rules of displacement DFOS sensor, way of installation, course of the study as well as the exemplary re-sults are discussed hereafter.

Time: March 30th, 14:15
Session: #7 - Geotechnics
Keywords: Shape Sensors, Strain, Displacement, Optical Fibres, DFOS, Composites, Footing, Geotechnics

[89] *Multidisciplinary investigation of a steel-concrete composite bridge*

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Paolo Borlenghi (Department of Architecture, Built environment and Construction engineering (DABC), Politecnico di Milano)
Manuel D'angelo (Department of Civil and Environmental Engineering (DICA), Politecnico di Milano)
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Marco Belloli (Department of Mechanical Engineering (MECC), Politecnico di Milano)
Carmelo Gentile (Department of Architecture, Built environment and Construction engineering (DABC), Politecnico di Milano)

Abstract. The paper presents the results from the multidisciplinary investigations performed on Baghetto Bridge. The structure, built in 1966, crosses the Adda river between the Municipalities of Castello dell'Acqua and Chiuro. It consists of three steel-concrete composite girders of different lengths supported by stone-masonry piers. The research program involved several investigations: (i) documentary research, (ii) ambient vibration testing, (iii) hydraulic study, and (iv) FE modelling and updating. After a concise review of the bridge history and a brief description of the structure, the hydraulic study based on existing topographic surveys is presented. This latter analyses allowed the estimation of hydraulic actions as well as the evaluation of possible hydro-geomorphologic scenarios. Subsequently, the complete results of the experimental tests are described and discussed. The modal parameters identified from the dynamic survey allowed validation of the numerical model, together with a more in-depth interpretation of the actual behaviour of the bridge. Moreover, the overall investigation allows to sound the presented multidisciplinary approach for the structural assessment of existing bridges.

Time: March 29th, 14:15
Session: #3 - Model Updating
Keywords: Bridge monitoring, Operational modal analysis, Model updating, River bridge, Scouring

[91] *Data Management in Structural Health Monitoring*

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Enrico Testi (University of Bologna)
Andrea Giorgetti (University of Bologna)

Abstract. With the advent of 5G and the future 6G networks, the increasing number of systems interconnected to the network, generates extremely huge amount of data. The autonomous structural health monitoring (SHM) of many structures and bridges represent an important sensor network application that generate a considerable amount of data that must be elaborated and managed. In such scenario, this paper proposes a set of machine learning (ML) tools to perform automatic feature selection and detection of anomalies in a bridge from vibrational data. As a case study, the Z-24 bridge is considered because of the extensive database of accelerometric measurements in both standard and dam- aged conditions. The proposed framework starts from the first two fundamental frequencies extracted through operational modal analysis (OMA) and clustering, followed by density-based time-domain tracking algorithm. The fundamental frequencies extracted are then fed to one class classifier (OCC) algorithms that perform anomaly detection. Finally the effect of reducing the number of sensors used to monitor the network, the number of bits used to quantize the accelerometric measurements, and the observation time is reported, with the purpose to reduce the amount of data stored without deteriorate the damage detection capability of the system. In numerical results a widely comparison of OCC algorithms is reported, more in detail, principal component analysis (PCA), kernel principal component analysis (KPCA), auto-associative neural networks (ANN) and one class classifier neural network (OCCNN2) are tested and their robustness is evaluated. In many cases, OCCNN2 algorithm increases the performance with respect to classical anomaly detection algorithms in terms of F1 score and accuracy. Moreover it is observed that only three sensors are enough to accomplish the anomaly detection task and also a reduced number of bit and observation time can be used without strongly affect the algorithms performance.

Time: March 29th, 10:15
Session: #1 - SS1: OMA and SHM
Keywords: Machine Learning, Neural Network, Structural Health Monitoring, Anomaly Detection, Big Data

[92] *Distributed fibre optic sensing for long-term monitoring of tunnel inner linings in anhydrite*

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Christoph M. Monsberger (Graz University of Technology)
Werner Lienhart (Graz University of Technology)

Abstract. Tunnels are civil engineering structures with a very long design lifetime of 100 years or more. In order to assess their long-term integrity monitoring systems with high robustness, long-term stability and high accuracy are required. Furthermore, monitoring should not disturb the operation of the traffic since tunnel closures are costly. This article discusses the design, installation and first results of a distributed fibre optic monitoring system installed in the inner lining of a railway tunnel. Five individual cross sections in an anhydrite area were equipped with the fibre optic monitoring system. Anhydrite regions can cause problems over a long time as water ingress causes anhydrite material to swell, which increases loads acting on the tunnel lining. All instrumented cross sections are connected to the central communication network of the tunnel and measurements can be conducted without interfering with the tunnel traffic. The developed approach focuses on long-term monitoring, which comprises special challenges regarding hardware, data processing and independent verification measurements to evaluate the long-term stability of the measurements. Additionally, issues such as cable bites by animals or forced changes of computer operating systems must be considered to guarantee the suitability of the monitoring system over decades.

Time: March 30th, 14:30
Session: #7 - Geotechnics
Keywords: distributed fibre optic sensing, long-term monitoring, strain distribution, anhydrite area

[93] *Long-term monitoring using GNSS: Lessons learned and experiences from 20 years of operation*

Caroline Schönberger (Graz University of Technology)
Werner Lienhart (Graz University of Technology)

Abstract. Global navigations satellite systems (GNSS) like GPS, Galileo, GLONASS and Beidou are used for monitoring of civil structures and natural phenomena since the 1980s. However, most of the implementations were either short term or realized in a very controlled environment.

In this article we report about the experiences of more than 20 years of GNSS based monitoring of a large scale object. In 1999 the GNSS monitoring system was developed and installed at a deep-seated gravitational slope movement in Austria and it is still operating.

The system gradually evolved during the years of operation to maintain a reliable operation and to take new developments of information and communication technology (ICT) into account. This included the change from radio communication to UTMS, the maintenance of the hardware (revision of GNSS stations, revision of solar collectors, exchange of batteries) and maintenance of software (Firmware updates of GNSS receiver, software updates, change-over to new operation systems). Especially the constant changes in the used software system results in maintenance time, which is often underestimated.

From these experiences we derive lessons learned which can be a guideline for other long term GNSS based monitoring systems.

Time: March 30th, 14:45
Session: #7 - Geotechnics
Keywords: GNSS monitoring system, ICT, Long-term monitoring, landslide, mass movement, early warning system

[94] *Assessment of similar reinforced concrete arch bridges by operational modal analysis and model updating*

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Carmelo Gentile (Politecnico di Milano, Dept. ABC)

Abstract. The Brivio bridge, built between June 1912 and May 1917, crosses the Adda river between the small towns of Brivio and Cisano Bergamasco, about 50 km North-East of Milan. The overall structure is 132.0 m long and consists of three reinforced concrete tied arches spanning 44.0 m each, with the arches being in principle perfectly equal; the three spans are supported by two piers, whose foundations are built in the river bed, and two end abutments.

As the historic bridge still represents a crucial node for the vehicular traffic in Lombardy and a joint research between Lombardy Region and Politecnico di Milano is ongoing to define guidelines for the assessment and maintenance of key infrastructures, it was decided to install a continuous dynamic monitoring system in the Brivio bridge.

Before the monitoring, preliminary investigations were carried out and included documentary research in the archives of Brivio town hall and National Roadway Authority (ANAS), visual inspection and geometric survey of the arches intrados, ambient vibration survey, mechanical characterization of the concrete materials (arches and hangers), finite element modeling of each span and vibration-based model tuning.

The present paper, after a concise summary of the multidisciplinary activities carried out on the different spans of the bridge, is mainly focused on structural modeling and vibration-based model updating; in order to take advantage of the similarity of the different tied arches, a simple system identification technique was used to update the models. The application of this technique provided optimal models accurately fitting the identified modal parameters of each bridge; in addition, the identified structural parameters are in good agreement with the available characterization of the materials.

Time: March 29th, 14:45
Session: #3 - Model Updating
Keywords: Arch Bridge, FE modelling and updating, Non-destructive testing, Operational modal analysis, Reinforced Concrete

[97] Digital environment for remote visual inspection and condition assessment of architectural heritage

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Andrea Ruggieri (Department of Biosciences and Territory, University of Molise)
Giovanni Fabbrocino (Department of Biosciences and Territory, University of Molise)

Abstract. The methods and the tools aimed to documenting and analysing the historical built heritage often follow different paths according to several disciplines in-volved in the knowledge process. Being aware about the importance that the scientific community confers to 3D digital representation of the buildings, we tried to find in this tool the hub able to connecting different languages. Therefore, the 3D digital model has represented and continues to be the privileged tool to ensure effective management of data derived from geometric-formal, diagnostic, archaeological and structural analyses, all aimed to subsequent restoration interventions.

Despite the certainty that this is the tool to be preferred, the time required to pro-duce 3D models often conflicts with the need to document quickly assets in emergency situations. In order to overcome this issue, we had the opportunity to test a tool, the virtual tour of the artefacts, which is placed in a time phase be-tween that of the survey and that one of the construction of the digital model and which represents a quick way to geolocalize, view and record data by remote visual inspection. The virtual tour, obtained from the 360° photos deriving from the survey campaigns with the laser scanner, properly processed, allows you to re-motely record the detected data on them, for example the damage analysis. The virtual tour, suitably enriched with contents, therefore turns into a connecting hub, and represents a versatile way of collaboration between various professionals, also lending itself to visualizing and recording information that can be implemented over time and which, if organized according to a logical and functional architecture, they provide a real opportunity for understanding the temporal evolution of the degradation phenomena on the wall surfaces.

Time: March 31st, 14:45
Session: #11 - Historical structures
Keywords: Digital survey, Image processing, Virtual Tour

[98] *Stange Overpass: Finite Element Model Updating of an unconventional railway bridge*

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Kultigin Demirlioglu (Oslo Metropolitan University)
Albert Lau (NTNU)
Kameran Aziz (Bane NOR)
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Endre Hyldmo (Bane NOR)
Tomislav Arsenovic (Bane NOR)
Enzo Martinelli (University of Salerno)

Abstract. Stange Overpass is a two-span railway reinforced concrete bridge on the Dovre line that connects the cities of Oslo and Trondheim in Norway. It was built in 1984 and has been extended by 1,5 meters in each direction in 2004. During the extension operation, the part of the deck that has been extended from the abutments had not been placed on a foundation but, instead, had directly been constructed over the soil mass. Within the context of the Intercity project that has recently been undertaken by the Norwegian Public Railroad Authority (BaneNOR), passenger trains that cross Stange Overpass will be upgraded to high-speed trains. For this, the existing bridge needs to be evaluated for the new train type. This requires a finite element model that correctly and reliably models the dynamic behavior of the bridge under various environmental and loading conditions. Preliminary analysis results show that the most significant parameter that governs the dynamic behavior of the bridge is the load-deformation behavior of the soil that directly supports the ends of the deck that extends outwards from the abutments. Further, the load-deformation behavior of the soil can be expected to be highly sensitive to the environmental conditions and the changes in these conditions from summer to Nordic winter. To provide a reliable estimate of the load-deformation behavior of soil as well as a reliable finite element model, an instrumentation set-up will be installed in the bridge by Oslo Metropolitan University in collaboration with BaneNOR. A new finite element model updating algorithm will be developed that can not only estimate the traditional linear parameters but also the non-linear force-deformation relationship of the soil mass underneath the bridge deck. This article provides a summary of the initial stages of the project including preliminary acceleration measurements in the bridge, sensitivity analysis that has been conducted to quantify the effects of the soil model on the bridge behavior and optimization of the instrumentation set-up.

Time: March 29th, 14:00
Session: #3 - Model Updating
Keywords: Finite Element Model Updating, Vibration-based monitoring, Railway Bridge

[101] *OMA: from research to engineering applications*

Salvatore Russotto (University of Palermo)
Alberto Di Matteo (University of Palermo)
Chiara Masnata (University of Palermo)
Antonina Pirrotta (University of Palermo)

Abstract. Ambient vibration modal identification, also known as Operational Modal Analysis (OMA), aims to identify the modal properties of a structure based on vibration data collected when the structure is under its operating conditions, i.e., when there is no initial excitation or known artificial excitation. This method for testing and/or monitoring historical buildings and civil structures, is particularly attractive for civil engineers concerned with the safety of complex historical structures. However, in practice, not only records of external force are missing, but uncertainties are involved to a significant extent. Hence, stochastic mechanics approaches are needed in combination with the identification methods to solve the problem. In this context, this paper's contribution is to introduce an innovative ambient identification method based on the Hilbert Transform to obtain the analytical representation of the system response in terms of the correlation function. This approach opens the pathway for a monitoring system that is user friendly and can be used by people who have little to no knowledge of signal processing and stochastic analysis such as those who are responsible for the maintenance of a city's historical buildings. In particular, this method operates in time domain only. Specifically, firstly the correlation functions matrix R_X (τ) is determined based on the recorded time domain data. Next, performing a Singular Value Decomposition (SVD) on R_X (τ) for τ=0 leads to an estimate of the modal matrix Φ containing all the modal shapes. In this manner, once Φ is known, the entire correlation functions matrix in modal space R_Y (τ) is recovered. Further, the analytical signals of the auto-correlation functions in modal space are determined performing the sum of each auto-correlation function with its Hilbert transform. Moreover, since the analytical signal can be expressed in terms of amplitude and phase, then frequencies and damping ratios estimation is possible. Finally, in order to prove the reliability of the method several numerical examples and an experimental test are reported.

Time: March 29th, 11:00
Session: #2 - SS1: OMA and SHM
Keywords: Operational Modal Analysis, Structural Identification, Correlation Function, Hilbert Transform, Analytical Signal

[103] *Time-Domain Damage Detection of Structures with Complex Modes under Variable Environmental Conditions Using Bayesian Virtual Sensors*

Jyrki Kullaa (Metropolia University of Applied Sciences)

Abstract. A direct time-domain algorithm for damage detection is introduced. It is based on hardware redundancy in which the number of sensors is greater than the number of excited modes plus the number of environmental variables. Therefore, for a structure with complex modes, the minimum number of sensors is foreseen to be higher that of the same structure with real modes. A two-step detection algorithm is proposed. First, the accuracy of each sensor is increased using Bayesian virtual sensing applied to each measurement independently. The more accurate Bayesian virtual sensors replace the physical sensors in the subsequent step. Second, the reading of each sensor is estimated using those of the remaining sensors by applying a model built from the training data under different environmental conditions. The residual is the difference between the actual sensor reading and the corresponding estimate and its increase beyond the threshold is an indication of damage. The algorithm was studied in a numerical experiment of a frame structure having a discrete damper element, which resulted in complex mode shapes. A com-parison was made with the same structure having real modes. It was shown that the required number of sensors indeed increased if complex modes were present. The performance of damage detection was studied with five damage levels using either actual measurements or virtual sensors. It was shown that virtual sensors outperformed the raw measurements and the performance of damage detection was higher with real modes.

Time: March 30th, 15:45
Session: #8 - Data Processing for SHM
Keywords: Complex modes, Virtual sensing, Bayes' rule, Damage detection, Hardware redundancy, Time-domain structural health monitoring

[105] *Numerical assessment on residual strength and displacement capacity of corroded RC columns*

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Mitsuyasu Iwanami (Tokyo Institute of Technology)
Nobuhiro Chijiwa (Tokyo Institute of Technology)
Kazuhide Nakayama (Tokyo Institute of Technology)

Abstract. Reinforcement corrosion is considered as the significant deterioration issue of RC structures in service. In this study, the effect of corrosion-induced damage on the structural performance of RC column is studied by the finite element method (FEM). Here, three dimensional (3D) non-linear finite element analysis is carried out using the software package COM 3. In the numerical analysis, corrosion-induced damage is modelled using different constitutive laws for corrosion-induced cracking, concrete and steel properties, and the bond between steel and concrete. The FEM model is validated using the experimental tests available in the literature. The load-deflection behavior and cracking patterns obtained from the FEM analysis are in good agreement with the experimental data. The findings of this study will be useful in assessing the residual structural performance of the RC columns with rebar corrosion.

Time: March 30th, 12:15
Session: #6 - SS3: New sensing technologies and strategies for civil SHM
Keywords: RC column, rebar corrosion, finite element method, residual structural performance

[106] *Use of SAR satellite data in bridge monitoring with application to urban areas*

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Abstract. In the last 20 years, SAR sensors installed on satellites have been increasingly used to monitor large scale phenomena such as subsidence, uplifting, or landslides. Recently several research groups started to investigate the use of remote sensing for damage detection in civil infrastructures. This technique presents in principle several advantages, not least the possibility to monitor a network of structures using the same sensor. However, its implementation for civil engineering projects is still at its infancy and a limited number of applications can be found in literature. The goal of this paper is to investigate the feasibility of using InSAR data for structural health monitoring of bridges with reference to a number of case studies. Data measured by radar satellites with different spatial and temporal resolutions and different frequency bands are processed to extract bridge displacement data and analyzed to identify possible structural damages. The SqueeSAR technique is used to extract displacement time histories from SAR images acquired by radar sensors with different spatial and temporal resolution (TerraSAR-X and RADARSAT 1-2). Displacements are then processed to identify anomalies possibly related to damage. Results show that high-resolution radar data enable the detection of very small structural displacements due to environmental changes, such as temperature variation.

Time: March 31st, 16:45
Session: #12 - SS2: SAR for civil SHM
Keywords: Satellite SAR Remote Sensing, Bridge Health Monitoring, Data Processing, SqueeSAR

[107] *Expeditious Dynamic Tests for the Estimation of Infill Masonry Wall Stiffness*

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Davide Arezzo (Università Politecnica delle Marche)
Sandro Carbonari (Università Politecnica delle Marche)
Fabrizio Gara (Università Politecnica delle Marche)

Abstract. The importance of assessing the overall behaviour of buildings considering the contribution of non-structural infills has been nowadays widely recognised. Indeed, infills can trigger fragile mechanisms of structural members preventing the evolution of dissipative mechanisms and can play an important role in the verifications at damageability limit states, especially in the case of strategic structures for which often high performance levels are re-quired, including the full operativity (i.e. absence of damage to both structural and non-structural members) after severe earthquake, in order to guarantee the building occupancy during the emergency management.

With reference to a case study, the paper presents a simplified approach for estimating the stiffness of masonry infill walls through expeditious dynamic impact tests on infills. The case study is constituted by a laboratory real-scale mock-up for which a complete dynamic identification is carried out before and after the realization of infill masonry walls. The adopted procedure is then validated through results from a refined finite element model of the mock-up in which infills are modelled adopting stiffnesses obtained from the proposed approach.

Time: March 29th, 12:15
Session: #2 - SS1: OMA and SHM
Keywords: Impact Load Tests, Ambient Vibration Tests, Experimental Modal Analysis, Operational Modal Analysis, Infill Masonry Wall Stiffness, Model Updating

[108] *Field evaluation of sensing sheet prototype exposed to cracking*

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Levent Aygun (Princeton University)
Matthew Gerber (Princeton University)
Campbell Weaver (Princeton University)
Sigurd Wagner (Princeton University)
Naveen Verma (Princeton University)
James Sturm (Princeton University)
Branko Glisic (Princeton University)

Abstract. Reliable crack detection and characterization is challenging. Sparsely spaced discrete strain sensors are insensitive to cracks if placed at even modest distances from damage. Improving spatial density of sensors significantly improves reliability in crack detection and characterization, but also significantly increases the costs associated with hardware, sensor installation, and data analysis and management. In the case of very large structures, one-dimensional distributed fiber optic sensors can be applied with reasonable costs, and while they significantly improve reliability in crack detection and characterization, they still cover only one dimension of a structure. In order to address the above challenges, two-dimensional sensor, called sensing sheet, have been developed. It consists of dense array of discrete sensors patterned over thin-film substrate, with integrated computational and power management circuits. The aim of this paper is to present field test performed on the sensing part of sensing sheet and evaluate its performance in crack detection and characterization in real-life settings. Two prototypes of sensing sheet were manufactured and tested. Each of them consisted of eight discrete full-bridge resistive strain sensors. One prototype was installed on the under-side of the superstructure of a deck stiffened arch and the other over existing shrinkage cracks on the foundation of Streicker Bridge. The behavior of the sensors was observed under daily temperature change. The test confirmed applicability of sensing sheet in real-life settings and its excellent performance in crack detection and characterization.

Time: March 30th, 11:00
Session: #6 - SS3: New sensing technologies and strategies for civil SHM
Keywords: Crack Monitoring, Sensing Sheet, 2D Quasi-distributed Sensor, Full-bridge Strain Sensor, Prestressed Concrete Bridge.

[109] *Long-Term Vibration Monitoring of the Sultan Ahmed Mosque in Istanbul*

Eser Cakti (Bogazici University, Kandilli Observatory and Earthquake Research Institute)
Kokcan Donmez (Bogazici University, Kandilli Observatory and Earthquake Research Institute)

Abstract. The 400-year-old Sultan Ahmed Mosque, aka the Blue Mosque, is one of Istanbul's most prominent historical structures. The primary structural system of the mosque consists of the main dome, four main arches and four semi-domes supporting the main dome; four pendentives, four main pillars and the secondary arches and piers that support the semi-domes. The structural health monitoring system on the Sultan Ahmet Mosque was installed in 2012. It consists of ten three-component accelerometers deployed at four different levels within the structure. Istanbul is in a seismically active region of Turkey. Istanbul shores are at about 20 km to the north of the segments of the North Anatolian Fault within the Marmara Sea. The mosque was damaged during the two M7+ earthquakes in 1766 and also in the M7.0 1894 earthquake. Since the deployment of the structural health monitoring system in October 2012, more than 200 earthquakes with local magnitudes varying from 2.1 to 6.6 have been recorded by the sensors in the mosque. This paper is about the time-domain and frequency-domain analyses of this data set with the aim of identifying dynamic response characteristics of the structure, its modal frequencies and their dependence on time, atmospheric conditions, earthquake magnitude and ground motion amplitude.

Time: March 31st, 14:30
Session: #11 - Historical structures
Keywords: Structural Health Monitoring, Modal Analysis, Historical Structures, Sultan Ahmed Mosque

[110] *Experimental Evidence for Structural Damage during the 30.10.2020 Samos-Sığacık Earthquake by Laser Vibrometry*

Eser Cakti (Bogazici University)
Sefer Ömercan Ertürk (Bogazici University)

Abstract. The Mw 6.9 earthquake of 30.10.2020 that took place to the immediate north of the island of Samos in the Aegean Sea was an important event. It was widely felt in the surrounding areas of both Turkey and Greece. It was an almost pure normal event and recorded by a significant number of strong motion stations deployed in the region. The event caused a small-scale tsunami that led to some damage in the shores of Sığacık, a neighbourhood of the İzmir province to the north of the earthquake source zone. Regional distribution of structural damage was parallel to the ground motion levels. However, the city of Izmir, the third largest city of Turkey and about 60 to 70 km to the north of the epicentral area was severely affected. 117 lives were lost and more than 500 buildings either collapsed or received heavy damage. The majority of collapses and casualties were in the Bayraklı district of İzmir, known for its poor site conditions.

This paper reports on a survey that we carried out soon after the earthquake in central Izmir. It relies on laser vibrometry, which was used to measure the dominant frequencies of a series of buildings in low, moderate and heavy damage state. Measurements were carried out remotely in 38 buildings. General structural characteristics of the buildings, such as number of stories, height, structural system and earthquake damage state were visually assessed. The dominant frequencies of vibration were estimated through analysis of vibration data. The fact that the majority of the buildings were more or less similar provided a unique opportunity for comparing their measured natural frequencies of vibration under different levels of damage.

Time: March 31st, 11:45
Session: #10 - SHM in earthquake prone regions
Keywords: Laser Vibrometry, Ambient Vibrations, Modal Frequency, Earthquake-induced Damage

[111] *Structural Monitoring and Dynamic Characterization of the Main Fire Station Building in Naples*

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Valerio Schiavone (Department of Structures for Engineering and Architecture - University of Napoli Federico II)
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Abstract. The main Firemen Station of Naples is a steel-concrete composite building structure, that is peculiar due to its suspended configuration and to the seismic devices installed at the time of construction. The latter represents one of the first Italian applications of vibration control systems and the assessment of seismic performance according to current codes is strongly needed. The installation of a static and dynamic monitoring system of the structure and the performing of a rising test of one seismic bearing could al-low to better understand the structural behaviour and to determine the best choice of seismic retrofit intervention of the building. A simplified structural model is developed to be used for predicting and evaluating the experimental results of dynamic shaking tests with vibrodine.

Time: March 31st, 12:00
Session: #10 - SHM in earthquake prone regions
Keywords: Structural Monitoring System, Suspended Structure, Seismic Control System, Strategic Structure

[113] *A structural engineering perspective on the use of remote sensing measurements for civil SHM*

Giovanni Fabbrocino (University of Molise)
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Carlo Rainieri (National Research Council of Italy)

Abstract. The last decades offered to the civil engineering scientific and technical community the opportunity to improve their diagnostic and assessment capability due to a significant sensing technology development. Many non-destructive testing techniques have been developed in a way that no-contact measurement can be taken, even in harsh environment. At the same time, dynamic testing and vibration-based monitoring are becoming very at-tractive for the health assessment of structures, also thanks to the increasing availability of powerful and compact devices able to perform complex cal-culations with low or moderate power demand. On the other hand, remote sensing techniques, which are currently well established for earth observation and therefore adopted in the assessment of large-scale geological phenomena, are increasing their resolution and capabilities of detailed description of changes in the configuration of the surface based on data collected by the satellite constellations. As a consequence of the enhanced observation capacity, their use for detailed monitoring of structures and infrastructures, not necessarily distributed in nature, has been largely debated by the technical and scientific community in recent years. Starting from these technological advances in the field of satellite measurements, the present paper reports some insights made by the research group on the use of remote sensing data for health monitoring of civil structures. In particular, attention is focussed on the approach to the data analysis. The applicative perspectives of remote sensing in the field of civil Structural Health Monitoring are finally discussed with reference to some explanatory cases.

Time: March 31st, 15:45
Session: #12 - SS2: SAR for civil SHM
Keywords: DinSAR, Remote sensing, Bridge monitoring

[114] *Forecasting and managing natural hazard induced risks on critical infrastructures in Southern Italy: the RAFAEL project*

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Sonia Giovinazzi (ENEA)

Abstract. RAFAEL is a project involving a vast Italian national partnership led by ENEA and participated by ANAS among several other organizations. RAFAEL aims to create a system for the forecast and analysis of real or end-user defined catastrophic events and for the assessment of the possible risks on critical infrastructures (including road, electricity, telecommunication, water networks) in terms of physical damages reduced/lost services, as well as for the evaluation of the cascading consequences for the served communities.

Towards that data are collected, collated and elaborated in term of Key Performance Indicators, KPI, from various types of sensors and from forecast systems, including among others, remote sensing, environmental sensors, seismic and geo-dynamic sensors and meteorological forecasts.

Damage and impact scenarios for events that might occur in the short-medium term are therefore elaborated and constantly updated with a continuous flow of upcoming data.

The RAFAEL system further to allowing to perform analysis based on real data for supporting the operational management of the emergency and response phases, it allows also to simulate end -user defined scenario for events such as earthquakes or extreme weather-induced events, and to evaluate the possible impacts and consequences for risk mitigation and contingency planning purposes.

Time: March 31st, 12:15
Session: #10 – SHM in earthquake prone regions
Keywords: natural hazard induced risks, critical infrastructures, sensors and forecast system

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