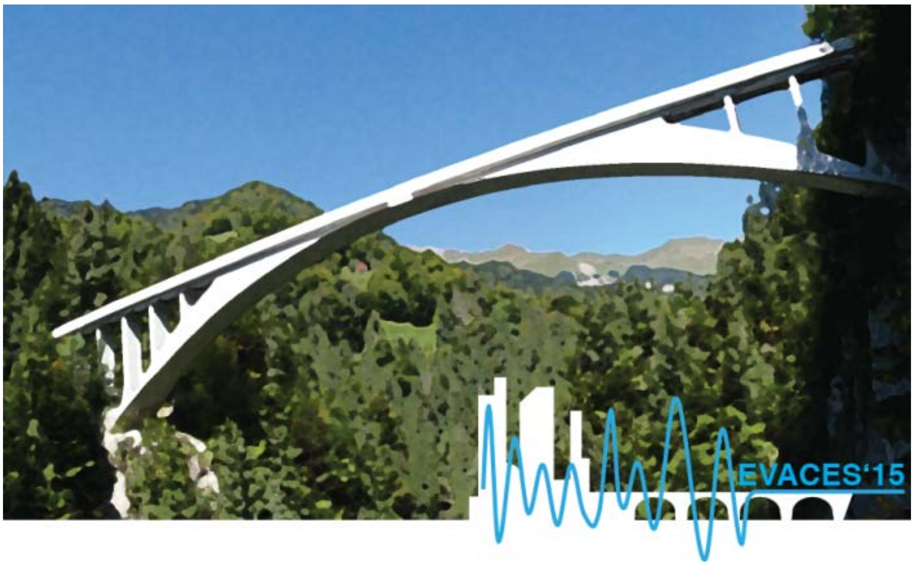
Materials Science & Technology

Zentrum für Wissenstransfer



EVACES’15

6th International Conference on Experimental Vibration Analysis for Civil Engineering Structures

Dübendorf (Zurich), Switzerland

October 19 – 21, 2015

Program

Edited by: Glauco Feltrin and Nadine Rieder, Empa

28 September 2015

Preface

The steady impressive progress of sensing and computer technology has dramatically changed our ability to acquire data about the vibration performance of civil structures. What decades ago was a complex activity provided by institutions that were big enough to afford an expensive instrumentation and a group of highly skilled experts is today the daily business of specialized small private companies. This extension of our capabilities to perform measurements on civil structures has provided deepened and enriched our knowledge about the performance of these structures under operational conditions. Many unexpected results have also sharpened our consciousness about the limitations of our standard analysis and design models. In the future information society data are expected to be one of the most important resources. The ability of collecting data about the performance of civil structures will there-fore further increase and probably involve more and more players without specialized skills. Data, however, are only in the minority of cases equivalent to information but the raw material from which information is extracted by a usually non-trivial analysis and interpretation process. While today analysis and interpretation is the realm of engineers in the future it's very likely that computer systems using artificial intelligence will increasingly perform fully automated data analysis and interpretation. Since civil structures are usually complex and unique and therefore less predictable than many other modern industrial products plenty of research will be needed to develop novel reliable measurement, data analysis and interpretation methods and tools which comply with the requirement of such fully automated systems.

EVACES, the International Conference on Experimental Vibration Analysis of Civil Engineering Structures, is the Forum where experts from all over the world have the opportunity to exchange their knowledge and experience about data acquisition, analysis and interpretation in the field of vibration of civil structures with the goal to contribute to the progress of science and technology. After the first edition in 2005 in Bordeaux (France), which was organized by the founder of EVACES Christian Cremona, four additional editions were held in a two years cycle in Porto (Portugal), Wroclaw (Poland), Varenna (Italy) and Ouro Preto (Brazil). Ten years after the first edition EVACES was held in Dübendorf, Switzerland, from October 19-21 and was organized by Empa, Swiss Federal Laboratories for Materials Science and Technology. For the first time the EVACES proceedings are published exclusively on an open access web platform with the scope to promote the dissemination and valorisation of the papers. We express our sincere thanks to the members of the Organizing Committee, the members of the Scientific Committee and in particular to all authors and participants for their essential and valuable contributions.

Paris and Dübendorf, September 2015 — Christian Cremona and Glauco Feltrin

Organization

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Glauco Feltrin

Organizing Committee

Glauco Feltrin, Empa

Nadine Rieder, Empa

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General Information

Dates

EVACES'15 will start on Monday, October 19th, and close on Wednesday, October 21st 2015.

Venue

The Empa Academy, which is situated in the Empa campus in Dübendorf, will host EVACES'15. The address of the Empa campus is

Überlandstrasse 129
CH-8600 Dübendorf
Switzerland

The address for satellite navigation devices is Eduard-Amstutz-Strasse, 8600 Dübendorf.

Registration and information desk

The registration and information desk will be open at the following hours:

Monday, October 19th:	9:00 to 18:00
Tuesday, October 20th:	8:00 to 16:00
Wednesday, October 21st:	8:00 to 15:00

Tel: +41 58 765 4220 or +41 58 765 4028.

Lunch and coffee-breaks

Lunch and coffee-breaks are included in the conference fee and are served at the Empa Academy.

Welcome cocktail

The welcome cocktail is included in the conference fee and is served at the Empa Academy on Monday evening at 18:15.

Conference banquet

The conference banquet will be held at the Schloss Greifensee on Tuesday, October 20th. Shuttle busses will provide the transfer from Empa campus to Schloss Greifensee and back. The departure time is at 16:30 and the arrival time back to Empa campus is at 22:30.

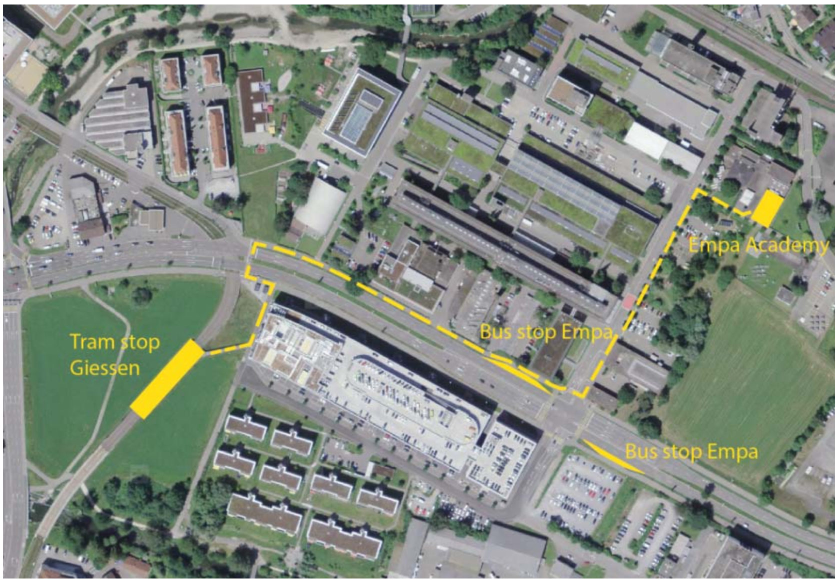
Internet

Wireless internet is available. The password can be obtained at the information desk.

Venue

The Empa Academy is the conference centre of Empa. It offers a broad range of education and information-exchange events for specialists in science and economy as well as for the public.

The Empa campus is connected to the public transportation network of the Zurich area. The tramway line 12 and the bus line 760 have stops, Dübendorf Giessen and Dübendorf Empa, in the neighbourhood of the Empa campus (see Figure below). The URL of the online timetable is https://www.stadt-zuerich.ch/vbz/en/index.html.



Information for tourists can be found on the Zürich Tourism Website http://www.zuerich.com/en.

Weather forecast for the Zurich area can be found at http://www.meteoswiss.admin.ch/home.html?tab=overview.

Program Overview

Monday 19 October 2015	Tuesday 20 October 2015	Wednesday 21 October 2015
9:00 – 18:00 Registration and information	8:00 – 16:00 Registration and information	8:00 – 15:00 Registration and information
9:30 – 10:00 Opening ceremony 10:00 – 10:45 Keynote lecture Prof. E. Chatzi	8:45 – 9:30 Keynote lecture Prof. S. Živanović 9:30 – 10:45 Sessions T1-1 and T1-2	8:45 – 9:30 Keynote lecture Dr. A. Andersson 9:30 – 10:45 Session W1-1
10:45 – 11:15 Coffee break	10:45 – 11:15 Coffee break	10:45 – 11:15 Coffee break
11:15 – 12:45 Sessions M1-1 and M1-2	11:15 – 12:45 Sessions T2-1 and T2-2	11:15 – 12:45 Sessions W2-1 and W2-2 12:45 – 13:00 Closing ceremony
12:45 – 14:15 Lunch	12:45 – 14:15 Lunch	13:00 – 14:30 Lunch
14:15 – 15:00 Keynote lecture Prof. E. Caetano 15:00 – 16:15 Sessions M2-1 and M2-2	14:15 – 15:00 Keynote lecture Dr. B. Weber 15:00 – 16:15 Sessions T3-1 and T3-2	
16:15 – 16:45 Coffee break	16:30 Departure for conference banquet	
16:45 – 18:15 Sessions M3-1 and M3-2		
18:15 Welcome cocktail		

Keynote lecture format

The keynote lectures are based on 35 minutes for paper presentation followed by 10 minutes of discussion.

Paper presentation format

The sessions are based on 15 minutes for paper presentations followed by 5 minutes of discussion.

Monday, 19 October 2015, 10:00 – 10:45
Keynote lecture

Room: Academy I
Chair: Glauco Feltrin, Empa, Switzerland

Structural identification and monitoring based on uncertain/limited information

Eleni N. Chatzi and Minas D. Spiridonakos

ETH Zürich, Institute of Structural Engineering, Zurich, Switzerland

The goal of the present study is to propose a structural identification framework able to exploit both vibrational response and operational condition information in extracting structural models, able to represent the system-specific structural behavior in its complete operational spectrum. In doing so, a scheme need be derived for the extraction of salient features, which are indicative of structural condition. Such a scheme should account for variations attributed to operational effects, such as environmental and operational load variations, and which likely lie within regular structural condition bounds, versus variations which indicate short- or long-term damage effects. The latter may be achieved via coupling of sparse, yet diverse, monitoring information with appropriate stochastic tools, able to infer the underlying dependences between the monitored input and output data. This in turn allows for extraction of quantities, or features, relating to structural condition, which may further be utilized as performance indicators. The computational tool developed herein for realizing such a framework, termed the PCE-ICA scheme, is based on the use of Polynomial Chaos Expansion (PCE) tool, along with an Independent Component Analysis (ICA) algorithm. The benefits of additionally fusing a data-driven system model will further be discussed for the case of complex structural response. The method is assessed via implementation on field data acquired from diverse structural systems, namely a benchmark bridge case study and a wind turbine tower structure, revealing a robust condition assessment tool.

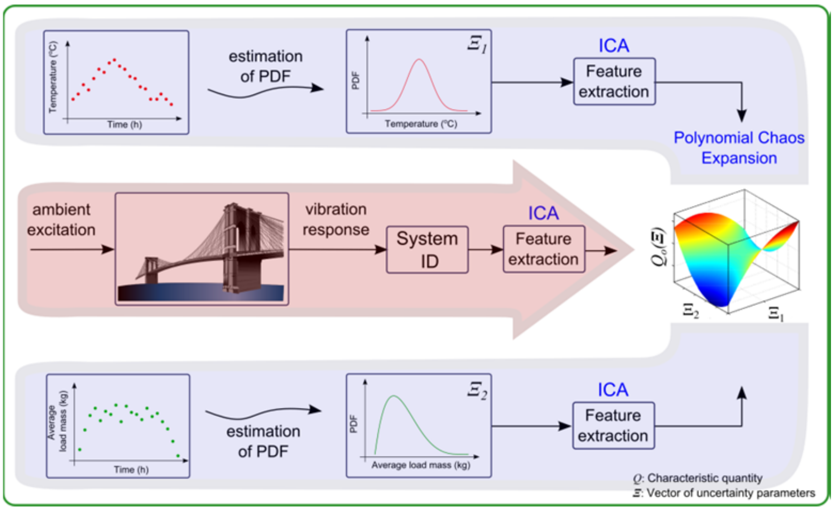


Figure 1. Schematic diagram of the proposed PCE-ICA identification approach.

Monday, 19 October 2015, 11:15 – 12:45

Session M1-1

Room: Academy I

Chair: Carmelo Gentile, Politecnico di Milano, Italy

Full scale monitoring of the twin chimneys of the Rovinari Power Plant

I. Bayati, M. Belloli, L. Rosa and A. Zasso

The presented paper deals with the structural identification and monitoring of two twin chimneys in very close arrangement. Due to twin arrangement, important interference effects are expected to modify the chimney response to wind action, causing vortex shedding and state-dependent excitation associated to the oscillatory motion of the leeward chimney, in and out of the windward chimney wake. The complexity of the physics of this problem is increased by the dependency of the aerodynamics of circular cylinders on Reynolds number; however, there is a weakness of literature about cylinders behaviour at critical and super-critical range of Reynolds number, due to experimental limitations. Also the International Committee on Industrial Chimneys (CICIND) does not provide, at present, any specific technical guideline about twin chimneys whose interaxis distance is less or equal two times the diameter, as in this case. For this reason a Tuned Mass Damper (TMD) has been installed in order to increase the damping of the chimney, as merely suggested. This work aims at assessing the effectiveness of the installed TMD and characterizing the tower dynamic behaviour itself due to the wind excitation, as well as providing full scale measurements for twin cylinders configuration at high Reynolds numbers.

Full scale monitoring of wind and traffic induced response of a suspension bridge

E. Cheynet, J. Bogunovic´ Jakobsen and J.T. Snæbjörnsson

This paper presents a full-scale analysis of wind and traffic induced vibrations of a long-span suspension bridge in complex terrain. Several wind and acceleration sensors have been installed along the main span on Lysefjord Bridge in Norway. In the present study, three days of continuous records are analysed. Traffic induced vibrations are dominant at low and moderated wind speed, with non-negligible effects on the overall bridge response for heavy vehicles only. Traffic and wind induced vibrations are compared in terms of root mean square of the acceleration response, and three simples approaches are proposed to isolate records dominated by wind-induced vibration. The first one relies on the separation of nocturnal and diurnal samples. The second one is based on the evaluation of the time-varying root mean square of the acceleration response. The last one evaluates the relative importance of the high frequency domain of the acceleration bridge response. It appears that traffic induced vibrations may have to be taken into account for the buffeting analysis of long-span bridge under moderated wind.

Wind-induced vibration experiment on solar wing

Y. Tamura , Y.C. Kim, A. Yoshida and T. Itoh

This paper describes wind tunnel experimental results of wind-induced responses of a solar wing system, and investigates its aeroelastic instability using a scaled model. The model comprised 12 solar wing units, each supported by 2 cables. The gaps between units were set constant. Two sag ratios (i.e. sag/span length) were adopted. The wind speed was varied from 0 to 16m/s, and 18 different wind speeds were used. From the experiment, when the sag was 2%, a sudden increase in fluctuating displacement was found near a mean wind speed of 10m/s at a wind direction of 40°. A sudden increase in fluctuating displacements was also found near a mean wind speed of 1m/s when the wind direction was larger than 60°. When the sag increased to 5%, some differences among units in mean displacements were found and complicate vibration in fluctuating displacement at low wind speed was observed.

Modal parameters identification and monitoring of two arches

M. Belloli, I. Bayati, S. Giappino, S. Muggiasca and L. Rosa

The paper presents the results of the modal parameters identification and of the continuous monitoring of two arches built in the new area of Expo 2015 in Milan. The activities on the arches were performed during the erection stage and they were planned as a consequence of preliminary studies performed at Politecnico di Milano wind tunnel that highlighted dynamic instability due to the wind. In particular, the first two bending modes of the structures showed a critical behaviour and for this reason a TMD (Tuned Mass Damping) system was designed in order to control these modes. At first, frequencies, damping and modal deflected shapes were evaluated in order to check the numerical FEM model, to tune the TMD system and to check its correct functioning. The two arches were then monitored for several months to observe their dynamic behaviour under different wind conditions. A good database about the strongest and the most frequent winds in the site was obtained. The accelerations registered under strong wind conditions did not reach dangerous levels for the structures, moreover these results showed a good agreement with the wind tunnel ones.

Monday, 19 October 2015, 11:15 – 12:45
Session M1-2
Room: Academy II
Chair: Joel P. Conte, Univ. of California, San Diego, USA

Pilot testing of a hydraulic bridge exciter

A. Andersson, M. Ülker-Kaustell, R. Borg, O. Dymén, A. Carolin and R. Karoumi

Within the research field of bridge dynamics, in-situ field measurements of existing structures often serve as a vital input in both understanding the real structural manner of action and updating mathematical models. Properties such as natural frequencies, mode shapes and damping ratios are commonly estimated. Experimental testing can be divided in two classes; input-output methods and output-only methods. Output-only methods are often the first choice for large structures e.g. bridges, due to complications in applying a significantly large known input load. Methods such as the stochastic subspace identification are often powerful for linear time-invariant systems. For some structures however, an amplitude dependent response may be observed due to nonlinearities. A category of such structures are railway bridges, where ambient vibrations from wind loads typically are much less than the response from passing trains. This paper describes the development of a hydraulic bridge exciter and its first pilot testing on a full scale railway bridge in service. The exciter is based on a hydraulic load cylinder with a capacity of 50 kN and is intended for controlled dynamic loading up to at least 50 Hz. The load is applied from underneath the bridge, enabling testing while the railway line is in service. The system is shown to produce constant load amplitude even at resonance. The exciter is used to experimentally determine frequency response functions at all sensor locations, which serve as valuable input for model updating and verification. An FE-model of the case study bridge has been developed that is in good agreement with the experimental results.

Using weigh-in-motion data to determine bridge dynamic amplification factor

J. Kalin, A. Žnidaric and M. Kreslin

The dynamic component of bridge traffic loading is commonly taken into account with a Dynamic Amplification Factor (DAF) – the ratio between the maximum dynamic and static load effects on a bridge. In the design codes, this factor is generally higher than in reality. While this is fine for new bridges that must account for various risks during their life-time, it imposes unnecessary conservativism into assessment of the existing well defined bridges. Therefore, analysis of existing bridges should apply more realistic DAF values. One way of obtaining them experimentally is by bridge weigh-in-motion (B-WIM) measurements, which use an existing instrumented bridge or culvert to weigh all crossing vehicles at highway speeds. The B-WIM system had been equipped with two methods of obtaining an approximation to the static response of the. The first method uses the sum of influence lines. This method relies on accurate axle identification, the failure of which can have a large influence on the DAF value. The other method uses a pre-determined low-pass filter to remove the dynamic component of the measured signal; however an expert is needed to set the filter parameters. A new approach that tries to eliminate these two drawbacks has been developed. In this approach the parameters for the filter are determined automatically by fitting the filtered response to the sum of the influence lines. The measurement of DAF on a typical bridge site agrees with experiments performed in the ARCHES [1] project: dynamic amplification decreases as static loading increases.

Measurement of the dynamic displacements of railway bridges using video technology

D. Ribeiro, R. Calçada, J. Ferreira and T. Martins

This article describes the development of a non-contact dynamic displacement measurement system for railway bridges based on video technology. The system, consisting of a high speed video camera, an optical lens, lighting lamps and a precision target, can perform measurements with high precision for distances from the camera to the target up to 25 m, with acquisition frame rates ranging from 64 fps to 500 fps, and be articulated with other measurement systems, which promotes its integration in structural health monitoring systems. The system's performance was evaluated based on two tests, one in the laboratory and other on the field. The laboratory test evaluated the performance of the system in measuring the displacement of a steel beam, subjected to a point load applied dynamically, for distances from the camera to the target between 3 m and 15 m. The field test allowed evaluating the system's performance in the dynamic measurement of the displacement of a point on the deck of a railway bridge, induced by passing trains at speeds between 160 km/h and 180 km/h, for distances from the camera to the target up to 25 m. The results show a very good agreement between the displacement measurement obtained with the video system and with a LVDT. The achieved precision was below 0.1 mm for distances from the camera to the target up to 15 m, and in the order of 0.25 mm for a distance of 25 m. The application of an image processing technique at subpixel level resulted in real precisions generally inferior to the theoretical precisions.

Surveying techniques in vibration measurement

P. Kuras

In order to determine the actual dynamic characteristics of engineering structures, it is necessary to perform direct measurements. The paper focuses on the problem of using various devices to measure vibration, with particular emphasis on surveying instruments. The main tool used in this study is the radar interferometer, which has been compared to: robotic total station, GNSS receivers and sensors (accelerometer and encoder). The results of four dynamic experiments are presented. They were performed on: industrial chimney, drilling tower, railway bridge and pedestrian footbridge. The obtained results have been discussed in terms of the requirements imposed by the standard ISO 4866:2010.

Monday, 19 October 2015, 14:15 – 15:00 **Room: Academy I**
Keynote lecture **Chair: Alexandre Cury, Univ. Federal de Juiz de Fora, Brazil**

Dynamic testing of cable structures

Elsa Caetano and Álvaro Cunha

Universidade do Porto, Faculty of Engineering, Porto, Portugal

The construction of lightweight structures covering progressively longer spans and employing cables as supporting elements has increased worldwide, leading to very flexible applications in bridges, roofs and special structures. These are generally characterised by complex structural behaviour, marked by a significant geometric nonlinearity, high deflections under service loads, a high number of vibration modes closely spaced in frequency, several of which of local nature, and proneness to vibrations induced by wind, traffic and human actions. The fact that the geometry and the structural behaviour of flexible lightweight structures is determined by the level of cable pre-stress makes their construction complex, demanding the accurate installation of pre-stress. This often determines the need for assessment of cable force during and after construction and is particularly relevant for roof structures and cable-stayed bridges. The paper discusses the role of dynamic testing in the study of cable structures. In this context, the identification of cable force based on vibration measurements is discussed. Using different examples from cable-stayed bridges, suspended roof structures and a guyed mast, it is shown that the combined application of simplified formulae with the numerical modelling and experimental identification of cable frequencies can be used to provide accurate estimates of the installed force in a wide range of spans, end conditions and for different cable diameters. Damping intervals of different types of cables are then presented and the assessment of vibrations is discussed, considering the typical requirements of structures with cables and the limitations and potential of existing instrumentation. Dynamic monitoring is finally introduced in the context of the assessment of the dynamic behaviour of a transmission line. The results from an implemented aerodynamic and structural monitoring system on a suspended roof are then shown, including the assessment of vibration amplitudes, the automatic identification of natural frequencies, mode shapes and damping ratios, and the correlation of these parameters with the wind velocity and temperature. The huge power of presently available instrumentation systems, identification algorithms, and the increased storage and data transmission capacities have enabled researchers and practitioners to develop tools to explore the complex dynamic behaviour of cable structures. The automatic identification of modal parameters, the assessment of response and the different correlations with wind and temperature provide an extremely powerful means to support the field validation of consecrated design tools entirely developed on the basis of wind tunnel tests.

Figure 1. International Guadiana Bridge, Portugal

Monday, 19 October 2015, 15:00 – 16:15
Session M2-1

Room: Academy I
Chair: Stefan Maas, Univ. du Luxembourg, Luxembourg.

Static and dynamic testing of a damaged post tensioned concrete beam

M.P. Limongelli, D. Siegert, E. Merliot, R. Vidal, J. Waeytens, F. Bourquin, V. Le Corvec, I. Gueguen and L.M. Cottineau

In this paper are reported the results of an experimental campaign carried out on a post tensioned concrete beam with the aim of investigating the possibility to detect early warning signs of deterioration basing on static and/or dynamic tests. The beam was tested in several configurations aimed to reproduce several different phases of the 'life' of the beam: the original undamaged state, increasing loss of tension in the post tensioning cables, a strengthening intervention carried out by means of a second tension cable, formation of further cracks on the strengthened beam. Responses of the beam were measured by an extensive set of instruments consisting of accelerometers, inclinometers, displacement transducers, strain gauges and optical fibres. The paper discusses the tests program and the dynamic characterization of the beam in the different damage scenarios. The modal properties of the beam in the different phases were recovered basing on the responses recorded on the beam during sine-sweep and impact hammer tests. The variation of the first modal frequency was studied to investigate the sensitivity of this parameter to both the cracking of the concrete section and the tension in the cables and also to compare results given by different types of experimental tests

Damage detection method for sleepers based on vibration properties

K. Matsuoka, T. Watanabe and M. Sogabe

In Japan, there are a lot of railways introducing PC sleepers which have been operated for several decades. For replace and manage a huge number of PC sleepers appropriately, the method to estimate the deterioration or damages of PC sleeper is required. In this study, in order to detect the damages of PC sleeper in the ballast track which cannot be inspected visually as shown on Fig 1, a damage detection method based on vibration mode characteristics of PC sleeper is developed. As a result of the vibration measurement test that conducted in parallel to the PC sleeper bending test, it is confirmed that the natural frequencies begin to decrease when the load of 1.2 times or more of crack load acted. And then, the vibration measurement test of PC sleepers which have actual damages and the vibration measurement test at the examination railway line were conducted. As the results, it can be confirmed that 3rd mode natural frequency in which the influence of damage appears greatly as shown on Fig. 2 and influence of ballast or rails don't appear is a suitable indicator for detection of damages such like the crack at the bottom of rail position Furthermore, towards the practical use, the damage detection by single point measurement and simple signal processing was considered, and it was shown that the same detection accuracy as multipoint measurement is securable.

Damage detection in concrete precast slabs: a quick assessment through modal tests

R.L. Pimentel, G.S. Ferreira, M.S. Gonçalves, D.S. Nyawako and P. Reynolds

The use of modal tests for detecting damage in reinforced concrete precast slabs is evaluated. A set of eight slabs were tested, each belonging to flats constructed for residential use. Two groups of slabs were identified and, in each group, both cracked and uncracked slabs were found. This made it possible to compare the responses of the slabs when subjected to modal tests. The tests were carried out employing an instrumented hammer and heel drops as excitation sources. Responses were measured using an accelerometer. The lowest natural frequencies of the slabs could be identified and after filtering the results, plots indicating the variation of the lowest natural frequency versus the number of cycles of free decay were obtained for each slab. Such a plot is of more general use than the value of the natural frequency by itself, as it does not depend on slab configuration. It was observed that the cracked slabs presented a similar pattern of variation of the natural frequencies throughout the decay, being distinctive from the pattern observed for their uncracked counterparts. This provided evidence that a quick assessment of the structural condition of such slabs through the use of the tests were feasible.

Monday, 19 October 2015, 15:00 – 16:15 Session M2-2

Room: Academy II Chair: Andreas Andersson, Royal Inst. of Tech., Sweden

Vibration reduction countermeasures of railway concrete viaduct

T. Watanabe, K. Matsuoka, M. Tokunaga and M. Sogabe

In this paper, numerical experiments about the structure borne sound countermeasures were conducted, by paying attention to the structure vibration of RC girder. Numerical experiments for the vehicle/track system model was carried out using the DIASTARSIII program, developed by the Railway Technical Research Institute, which analyses dynamic interaction between the vehicle and railway structure. Also, numerical analysis for the track/structure system model was carried out using the DIARIST program for the track structure. As a result, we elucidated the vibration reduction effect of various countermeasures. First, vibration reduction effect of soft track pad of 30MN/m is recognized in the frequency band above about 70 Hz by measurement results and analysis results. Second, the frequency band which obtained reduction effect depends a great deal on natural frequency of vibration-reducing track.

Dynamic analysis of elevated viaducts of Doha Metro Green Line

E. Ayoub, S. Mehanny, C. Malek and G. Helmy

The 2.7 kilometres double track elevated viaducts of Doha metro green line, currently under construction, consist of cast-in-situ and precast segmental simply supported spans ranging from 20 to 35 m and continuous cast-in-situ two and three spans (30-57 m), (50-51-44 m) and (37-68-37 m) U-trough decks. The non-typical configuration of the continuous span arrangements was imposed to the designer by existing underneath utilities and infrastructures. In order to ensure the passenger comfort and traffic safety by preventing track instability during train operation for this special landmark project, performing a dynamic analysis was vital. The dynamic analysis focuses on the vertical accelerations and vertical displacements as well as lateral frequencies of vibration. All simply supported spans as well as the continuous spans of the project are considered. The real train of the project composed of 6 vehicles with a total length of 120m and with actual axle loads (maximum axle load of 160 kN with 4 axles per vehicle) is adopted in the dynamic analysis. The analysis is carried out using both direct time integration of the equation of motion and modal time history analysis for different train speeds ranging from 60 km/hr to the maximum permissible speed along the metro line (160 km/hr) with the maximum operating speed ranging from 100 to 130 km/hr. For each train speed the maximum vertical acceleration and the maximum vertical deflection are monitored using the CSI bridge software and are compared to the allowable values given in EN 1991-2 and EN 1990-Annex 2. According to relevant Eurocode requirements, the vertical accelerations and the vertical deflections were found acceptable for all segments of the elevated viaduct.

Numerical analysis on variation of dynamic response of girder bridges with torsional reinforcement panels

J.-Y. Kang, J.-W. Kwark, S.-Y. Park and K.T. Kim

The dynamic flexural behaviour of the railway bridge is influenced by its torsional behaviour. Especially, in the case of girder railway bridges, the dynamic response tends to amplify when the natural frequency in flexure (1st vibration mode) is close to that in torsion (2nd vibration mode). In order to prevent such situation, it is necessary to adopt a flexural-to-torsional natural frequency ratio larger than 120%. This study proposes a solution shifting the natural frequency in torsion to high frequency range and restraining torsion by installing concrete panels on the bottom flange of the girder so as to prevent the superposition of the responses in the girder bridge. The applicability of this solution is examined by finite element analysis of the shift of the torsional natural frequency and change in the dynamic response according to the installation of the concrete panels. The analytical results for a 30 m-span girder railway bridge indicate that installing the concrete panels increases the natural frequency in torsion by restraining the torsional behaviour and reduces also the overall dynamic response. It is seen that the installation of 100 mm-thick concrete panels along a section of 4 m at both extremities of the girder can reduce the dynamic response by more than 30%.

Monday, 19 October 2015, 16:45 – 18:15
Session M3-1
Room: Academy I
Chair: Álvaro Cunha, Universidade do Porto, Portugal

On the advances of automatic modal identification for SHM

R. Cardoso, A. Cury and F. Barbosa

Structural health monitoring of civil infrastructures has great practical importance for engineers, owners and stakeholders. Numerous researches have been carried out using long-term monitoring, for instance the Rio-Niterói Bridge in Brazil, the former Z24 Bridge in Switzerland, the Millau Bridge in France, among others. In fact, some structures are monitored 24/7 in order to supply dynamic measurements that can be used for the identification of structural problems such as the presence of cracks, excessive vibration, damage identification or even to perform a quite extensive structural evaluation concerning its reliability and life cycle. The outputs of such an analysis, commonly entitled modal identification are the so-called modal parameters, i.e. natural frequencies, damping rations and mode shapes. Therefore, the development and validation of tools for the automatic identification of modal parameters based on the structural responses during normal operation is fundamental, as the success of subsequent damage detection algorithms depends on the accuracy of the modal parameters estimates. The proposed methodology uses the data driven stochastic subspace identification method (SSI-DATA), which is then complemented by a novel procedure developed for the automatic analysis of the stabilization diagrams provided by the SSI-DATA method. The efficiency of the proposed approach is attested via experimental investigations on a simply supported beam tested in laboratory and on a motorway bridge.

Non-destructive evaluation method based on dynamic invariant stress resultants

J. Zhang, L.R. Barroso, S. Hurlebaus and N. Stubbs

Most of the vibration based damage detection methods are based on changes in frequencies, mode shapes, mode shape curvature, and flexibilities. These methods are limited and typically can only detect the presence and location of damage. Current methods seldom can identify the exact severity of damage to structures. This paper will present research in the development of a new non-destructive evaluation method to identify the existence, location, and severity of damage for structural systems. The method utilizes the concept of invariant stress resultants (ISR). The basic concept of ISR is that at any given cross section the resultant internal force distribution in a structural member is not affected by the inflicted damage. The method utilizes dynamic analysis of the structure to simulate direct measurements of acceleration, velocity and displacement simultaneously. The proposed dynamic ISR method is developed and utilized to detect the damage of corresponding changes in mass, damping and stiffness. The objectives of this research are to develop the basic theory of the dynamic ISR method, apply it to the specific types of structures, and verify the accuracy of the developed theory. Numerical results that demonstrate the application of the method will reflect the advanced sensitivity and accuracy in characterizing multiple damage locations.

Bayesian methods for nonlinear system identification of civil structures

J.P. Conte, R. Astroza and H. Ebrahimian

This paper presents a new framework for the identification of mechanics-based nonlinear finite element (FE) models of civil structures using Bayesian methods. In this approach, recursive Bayesian estimation methods are utilized to update an advanced nonlinear FE model of the structure using the input-output dynamic data recorded during an earthquake event. Capable of capturing the complex damage mechanisms and failure modes of the structural system, the updated nonlinear FE model can be used to evaluate the state of health of the structure after a damage-inducing event. To update the unknown time-invariant parameters of the FE model, three alternative stochastic filtering methods are used: the extended Kalman filter (EKF), the unscented Kalman filter (UKF), and the iterated extended Kalman filter (IEKF). For those estimation methods that require the computation of structural FE response sensitivities with respect to the unknown modeling parameters (EKF and IEKF), the accurate and computationally efficient direct differentiation method (DDM) is used. A three-dimensional five-story two-by-one bay reinforced concrete (RC) frame is used to illustrate the performance of the framework and compare the performance of the different filters in terms of convergence, accuracy, and robustness. Excellent estimation results are obtained with the UKF, EKF, and IEKF. Because of the analytical linearization used in the EKF and IEKF, abrupt and large jumps in the estimates of the modeling parameters are observed when using these filters. The UKF slightly outperforms the EKF and IEKF.

Monday, 19 October 2015, 16:45 – 18:15
Session M3-2

Room: Academy II
Chair: Roberto Pimentel, Univ. Federal da Paraiba, Brazil

Vibration monitoring of a large scale heavy haul railway viaduct

F. Busatta and P. Moyo

In South Africa, heavy haul railway transport was introduced in the middle of the 1970s for the Iron Ore and the Coal Export lines. In recent decades the expansion of mining areas and the emergence of new markets coupled with a strong demand for iron ore and coal have led to progressive increase in the capacity of the export lines through improving operational efficiencies and raising the rail traffic volumes. As a consequence of the increased rail traffic, civil engineering structures along the export lines are now crossed by heavier and longer trains with more and more trains passages than in the past. However, existing railway structures are aging and accelerated deterioration as well as structural defects might arise when bridges are crossed by heavier and/or faster freight trains. Thus, stakeholders have recognized the importance of estimating future enhancements and capacity expansions of heavy haul lines in SA based on accurate structural assessments of the existing railway structures and appropriate interventions. The paper deals with the Olifants River Viaduct, one of the most critical railway structures along the Iron Ore Export Line in South Africa. The viaduct, built in 1976, is a prestressed concrete structure, 1035 m long on 23 equally spaced spans. Since 2007, with the introduction of a new Radio Distributed Power train, the viaduct is crossed by the longest freight train in the world (≈ 4.1 km long) with axle load equals 300 kN (30 tonnes). Since some cracking phenomena have occurred inside the viaduct girder and a further increase of rail traffic on the Iron Ore Line is planned in the near future, some investigations have been performed on the viaduct and a permanent monitoring system have been designed. The paper presents and discusses the vibration tests carried out on the viaduct to implement the monitoring system which includes accelerometers, dynamic strain transducers, crack sensors and thermocouples to monitor the structural condition and vibration response of the viaduct over time.

Vibration based structural assessment of the rehabilitation intervention in r.c. segmental bridge

P. Franchetti, M. Frizzarin, A. Leonardi and F. Zeni

A vibration based structural assessment campaign was carried out on a r.c. segmental bridge in North East Italy. The bridge is 180 m long, with a central span of 83 m, and two piers with a height of 50 m. The piers and the deck are composed by a box girder made by precast segments of post-tensioned reinforced concrete. The bridge has a cantilever static scheme, fixed at the top of the piers and with a hinge at the centre of the span. The particular configuration of the hinge consists in a couple of steel elements, each one composed by a tongue and groove joint. Since the year 1960, when the bridge was built, during the huge amount of cycles of rotation and horizontal displacements, the hinge was subjected to consumption and degradation, which caused a malfunctioning of the device. In particular the passage of heavy trucks on the bridge was causing large oscillation and hammering between the two parts of the structures, with consequent structural damage. An intervention of rehabilitation of the bridge led to a reinforcement of the existing hinges with the coupling of new metallic devices. The intervention was rapid and didn't involve large demolitions; new tongue and groove hinges were applied, that by one side allow the horizontal displacements and rotation, by the other side strongly reduce the relative vertical displacements of the two parts of the bridge. A dynamic test campaign was set up in order to assess the effectiveness of the intervention: 8 accelerometers were applied to the structure and the ambient vibrations were measured and analysed. The principal dynamic parameters were calculated and analysed with respect to the intervention that was realized. The tests clearly showed the effectiveness of the intervention, and helped the designer to have a better understanding of the structural behaviour of the bridge.

Operational modal analysis of a road-rail bridge

M. Cardoso, R.A.C. Sampaio, R.M. de Souza and E. Silva

In this paper, we describe an Operational Modal Analysis (OMA) of the Bridge over the Tocantins River, a composite road-rail bridge located in the city of Marabá, state of Pará, northern Brazil. The bridge is part of the Carajás Railway, which is used by VALE Company to transport iron ore from "Serra dos Carajás", the largest mineral reserve of the planet. The bridge has a length of 2310m, being the second longest road-rail bridge in Brazil. The study focused on the bridge central span (with 77 m of length) and two adjacent spans (with 44 m of length). We employed Piezo-electric accelerometers to measure the dynamic response of the bridge under ambient excitation, which consisted of the passage of loaded and unloaded trains, road traffic, wind and river current. For modal identification, to avoid the influence of the train mass over the bridge system, we only considered acceleration signals of road traffic and signals corresponding to intervals after the passage of loaded trains, i.e., the study disregarded the intervals during which the trains were over the monitored spans. We obtained modal parameters through two identification methods: one in the time domain and other in the frequency domain. We also performed a comparative analysis between the experimental modal parameters, and the numerical results obtained with a finite element model provided by a third-part company.

Vibration monitoring of long bridges and their expansion joints and seismic devices

K. Islami

This paper presents a number of recently installed Structural Health Monitoring (SHM) systems: a) on a 2km double suspension bridge, b) on a long railway viaduct that has experienced cracking and c) on a steel arch bridge under seismic activity. Damage detection techniques have been applied through high-frequency measurements of vibrations, pressure and strain, thus enabling a proper understanding of the structures' behavior. For example, 25 kHz vibrations are measured at the expansion joints of a double suspension bridge enabling damages to be detected at an early stage by recording the level of accelerations and natural frequencies under traffic. The availability of such systems has now led to the development of "smart" expansion joints: expansion joints that feature an integrated advanced monitoring system, already when fabricated. The second case study illustrates the monitoring of a recently built high-speed-railway viaduct subjected to early cracking. Extensive analyses have been performed and especially correlations between crack opening and accelerations, under high-speed trains, have shown that the cracking activity is largely discontinued. Finally, the seismic retrofitting of an arch bridge has been tested by a SHM system permanently measuring accelerations of the deck and pressure inside the shock transmission units (STU) at 100Hz frequency. Analysis of the data shows, somewhat surprisingly, that the seismic devices are quite sensitive to vehicles crossing the bridge. The pressure signals coming from the eight STUs rigidly connected to the structure and the accelerometers demonstrated this. In conclusion, these non-standard monitoring for civil structures will demonstrate the usefulness of SHM in assessing and maintaining not only the entire structures but also their key functional elements.

Tuesday, 20 October 2015, 8:45 – 9:30 **Room: Academy I**

Keynote lecture **Chair: Álvaro Cunha, Universidade do Porto, Portugal**

Modelling human actions on lightweight structures: experimental and numerical developments

Stana Živanović

University of Warwick, School of Engineering, Coventry, United Kingdom

Improved strength of contemporary construction materials (the latest being fibre-reinforced polymer) allows architects and structural designers to experiment with structural forms and span ever greater distances. This development results in innovative, light, slender and aesthetically appealing structural solutions that often represent city landmarks and attraction for visitors (Figure 1). When these modern structures are exposed to dynamic excitation generated by human activities, which is a frequently encountered loading scenario on footbridges, floors, grandstands and staircases, they might experience excessive vibrations. The liveliness is primarily a consequence of the structures being lightly damped and having one or more vibration modes that are excitable by humans walking, jumping, bobbing, dancing, running or swaying.

Figure 1. The Millennium Bridge, London and the Millennium Stadium, Cardiff.

Until recently, human actions on the structures have been considered by focussing exclusively on a forcing harmonic with potential to excite resonance, and assuming that the dynamic force is independent from the vibration response. While this simplified modelling was sufficient for assessment of vibration performance of more robust structures a few decades ago, it was exposed when more slender structures came into use and emphasised the need for development of higher fidelity models. These new models are expected not only to describe both temporal and spectral features of the force signal more accurately, but also to capture the influence, psychological and physiological, of human-structure and human-human interaction mechanisms on the human kinematics, and consequently on the force generated and the resulting vibration response. This paper identifies four challenges encountered in the formulation of new generation of the models, reports the key developments and identifies the scope for further research.

The four challenges are to accurately represent:

1. Randomness in the human dynamic loading,
2. Human-structure interaction (HSI),
3. Human-human interaction (HHI), and
4. Human perception and response to vibration.

This keynote paper discusses, to various level of detail, the four challenges and their importance for successful modelling of human (walking and bobbing) actions and the resulting ground reaction force (GRF) induced into the supporting structure. It reports on development of both oscillator and bipedal models and offers insight into novel results of experimental studies on a laboratory structure at the University of Warwick aimed at quantifying human interaction with the oscillating bridge deck. The paper shows that a rapid development of the pedestrian modelling strategies was made over the last 15 years. From modelling a human dynamic force exclusively by means of the Fourier harmonic components, the modelling diversified to accommodate randomness in the dynamic force and include human-structure integration to the point that some of these approaches have already been incorporated in the contemporary design practice. Finally, the paper formulates questions for further research, and emphasises the need for further experimental work in the quest to support extensive theoretical developments. Successful calibration and verification of the latest models will open routes for their introduction into the structural engineering design practice.

Tuesday, 20 October 2015, 9:30 – 10:45
Session T1-1

Room: Academy I
Chair: Marco Belloli, Politecnico di Milano, Italy

The dynamic behaviour of the mammoth in the Spanish Fortress, L'Aquila, Italy

F. Casarin, E. Beccaro, M. Fattoretto, P. Girardello and M. Caldon

The fossil remains of a "Mammuthus Meridionalis" were found the 25th of march 1954 in a lime quarry close to the city of L'Aquila. The Mammoth skeleton was soon "reconstructed" on a forged iron frame, and it was located in one of the main halls of the Spanish fortress in L'Aquila. A comprehensive restoration was recently completed (2013-2015), also considering the study of the adequacy of the supporting frame, which demonstrated to survive the relevant 2009 l'Aquila earthquake. After a laser-scanner survey, allowing to build a very detailed Finite Element model, Operational Modal Analysis was employed in order to obtain the dynamic identification of the structure. Results of the experimental activities explained the capacity of the structure to bear the 2009 main shock, since the natural frequencies demonstrated to be quite reduced. The structure acted as a "natural" seismic device, avoiding to reach its Ultimate Limit State however paying the toll of relevant displacements. The seismic motion caused several cracks at the edge of the bones, indicating the non-fulfilment of the ALS (damage Limit State of Artistic contents). A proposal for seismic isolation and redesign of the supporting frame was then discussed. The paper illustrates the scientific activities assisting the restoration intervention, entailing a multidisciplinary approach, in the fields of restoration, palaeontology and seismic engineering.

One-year dynamic monitoring of a masonry tower

M. Guidobaldi, C. Gentile and A. Saisi

The paper presents some results of the continuous dynamic monitoring program carried out on the tallest historic tower in Mantua, Italy. This project follows an extensive diagnostic investigation aimed at assessing the structural condition of the tower after the Italian earthquakes of May 2012. A simple dynamic monitoring system was permanently installed in the upper part of the building and automatic modal identification was performed. The results allow to evaluate the effects of changing temperature on automatically identified natural frequencies, to verify the practical feasibility of damage detection methods based on natural frequencies shifts and provide clear evidence of the possible key role of continuous dynamic monitoring in the preventive conservation of historic towers.

Vibration-based SHM for cultural heritage preservation: the case of the S. Pietro bell tower in Perugia

G. Comanducci, N. Cavalagli and F. Ubertini

In the present work, multivariate statistical analysis techniques are newly applied in the field of condition assessment of cultural heritage structures. More specifically, the paper presents the design and the implementation of an SHM system for the bell-tower of the Basilica of San Pietro, one of the most relevant monuments of the city of Perugia, Italy. The system comprises three high-sensitivity accelerometers permanently installed on top of the tower and a remote server that automatically processes the data so as to acquire modal parameters and to use such information for novelty analysis and health assessment. In the paper, after a brief description of the permanent monitoring system installed on the structure and of the adopted SHM strategy, the results of the first months of continuous monitoring are presented. Later on, the potential capability of the aforementioned statistical techniques in damage detection is verified by using the continuously identified eigen-frequencies of the bell tower.

Tuesday, 20. October 2015, 9:30 – 10:45

Session T1-2

Room: Academy II

Chair: Glauco Feltrin, Empa, Switzerland

Some remarks on the influence of temperature-variations, non-linearities, repeatability and ageing on modal-analysis for structural health monitoring of real bridges

S. Maas, S. Schommer, V.-H. Nguyen, D. Waldmann, J. Mahowald and A. Zürbes

Structural Health Monitoring (SHM) intends to identify damage by changes of characteristics as for instance the modal parameters. The eigenfrequencies, mode-shapes and damping-values are either directly used as damage indicators or the changes of derived parameters are analysed, such as e.g. flexibilities or updated finite element models. One common way is a continuous monitoring under environmental excitation forces, such as wind or traffic, i.e. the so-called output-only modal analysis. Alternatively, a forced measured external excitation in distinct time-intervals may be used for input-output modal analysis. Both methods are limited by the precision or the repeatability under real-life conditions at site. The paper will summarize several field tests of artificially step-by-step damaged bridges prior to their final demolishment and it will show the changes of eigenfrequencies due to induced artificial damage. Additionally, some results of a monitoring campaign of a healthy bridge in Luxembourg are presented. Reinforced concrete shows non-linear behaviour in the sense that modal parameters depend on the excitation force amplitude, i.e. higher forces lead often to lower eigenfrequencies than smaller forces. Furthermore, the temperature of real bridges is neither constant in space nor in time, while for instance the stiffness of asphalt is strongly dependant on it. Finally, ageing as such can also change a bridge's stiffness and its modal parameters, e.g. because creep and shrinkage of concrete or ageing of elastomeric bearing pads influence their modulus of elasticity. These effects cannot be considered as damage, though they influence the measurement of modal parameters and hinder damage detection.

Investigation of tension forces in a stay cable system of a road bridge using vibration methods

P. Hawryszków

In the article author presents method of investigation of tension forces in stay cable systems using dynamical methods. Research was carried out during stay cable system installation on WN-24 viaduct near Poznań. Thus it was possible to compare tension forces indicated directly by devices using for tensioning of cable-stayed bridges with results achieved indirectly by means of dynamical methods. Discussion of results was presented. Advantages of dynamical methods and possible fields of application were described. This method, which has been rarely used before, might be an interesting alternative in diagnostics of bridges in comparison to traditional methods.

Investigation of temperature-dependent stiffness variation of a layer of asphalt and their possible effect on the deformation behaviour of concrete structures

D. Erdenebat, F. Scherbaum, D. Waldmann, S. Maas and A. Zürbes

In the time of increasing maintenance costs, the continuous inspection and the earliest possible damage detection become more and more important. In order to minimize future maintenance costs, the exact evaluation of the condition of the structure and the exact assessment of potential damages are of essential importance. Therefore the University of Luxembourg carries out projects to investigate an efficient application of different assessment methods taking into account praxis relevant test conditions. As a part of this project especially the changing temperatures which influence the stiffness of the materials are analysed. As a consequence, for the condition assessment of structures, the asphalt layer cannot only be taken into consideration as a mass applied as load on the structure. Due to bond effects of the asphalt layer to the load carrying element its changing stiffness induced by changing temperatures influences the stiffness of the whole structure. Within this paper this effect will be illustrated. First the load carrying behaviour and the stiffness of pre-stressed concrete slabs realized with and without an additional asphalt layer will be investigated in a climate chamber and the results will be compared for different temperatures.

Tuesday, 20 October 2015, 11:15 – 12:45
Session T2-1

Room: Academy I
Chair: Elsa Caetano, Universidade do Porto, Portugal

Dynamic investigation of a suspension footbridge using accelerometers and microwave interferometer

C. Gentile

The paper presents the main results of the serviceability assessment of a lively suspension footbridge. An ambient vibration test was firstly developed on July 2012 using conventional accelerometers with the objective of identifying the baseline dynamic characteristics of the structure; subsequently, groups of volunteers (up to 32 adults) simulated normal walking and running at different step rates along the deck and the human-induced vibrations were simultaneously measured by accelerometers and microwave interferometer. The deflection responses recorded by the microwave interferometer suggested the exceeding of comfort criteria threshold and this result was confirmed by the acceleration levels directly measured by accelerometers or derived from the (radar) displacement data. Furthermore, a second ambient vibration test was performed in Autumn 2012 using only the microwave interferometer: the natural frequencies of the footbridge generally exhibited not negligible variations, that were conceivably associated to the change of suspension forces induced by temperature, so that special care is suggested in the design of the devices aimed at mitigating the excess of human induced vibrations observed in the footbridge.

Structural health monitoring of grandstands: a review

M.A. Gómez-Casero Fuentes, R. Castro-Triguero, E. García-Macías, R. Gallego Sevilla and J. Cabrera

This article is a state of the art about Grandstands. The Grandstands are slender structures designed to accommodate a large number of people, which are especially under the actions of wind and the human-structure interaction. Over the years, it has been discuss of this topic, although still the number of publications still remain low. The human-structure interaction is a complex issue, where the loads may have different behaviours, depending many factors, including: type of audience (active or passive), public behavior (jumping, walking, running, clapping, vandal loads), type of event (sports, concerts, meeting), position and posture of the individual, even influences the type of seat (with or without back, stiffness). However, the structure will behave differently when empty or fully occupied. Another load to consider is the wind, especially when the structure has a roof, screens, large-scale advertising, etc. These two types of loads can interact together, which implies an increase in the normal number of load combinations to consider. There are biomechanical models of human behaviour, used for design these types of structures. In addition, there are mathematical models to simulate the behaviour of the Grandstands by numerical methods. In recent years, all these models are throwing good results, against laboratory tests performed. It has also been monitored real Grandstands. This paper compiles all existing information on this topic.

Damping and frequency of human-structure interaction system

E. Ahmadi and C. Caprani

Human presence can change the dynamic characteristics of human-structure interaction systems, i.e. particularly their damping and frequency. In many design codes, the pedestrian is regarded as a moving force (MF) while a more complete model, referred to as moving spring-mass-damper (MSMD) has received attention recently. Unlike the MF model, the MSMD model is able to take into account the human damping and stiffness effects. This paper is devoted to determining the instantaneous damping and frequency of the human-structure interaction (HSI) system subjected to a single and multiple pedestrians. Each pedestrian is modelled as a MSMD, and a methodology for determining the system damping and frequency properties is described. A simply supported beam structure is considered and modelled in modal space. The imparted pedestrian vertical force is modelled adopting the first four harmonics of Fourier representation using Young's dynamic load factors. It is concluded that human presence can significantly increase and decrease damping and frequency of the structure, respectively and it is so important to consider human effect on the system's damping and frequency in serviceability assessment of footbridges.

Experimental and numerical assessment of the dynamical behaviour of a footbridge under human-induced loads

J.G.S. da Silva, G.L. Debona and C.M.R. Gaspar

The main objective of this research work is to perform an experimental and numerical assessment of an existing pedestrian footbridge located in the campus of the State University of Rio de Janeiro (UERJ), Rio de Janeiro/RJ, Brazil. The structural system is based on an internal reinforced concrete footbridge spanning 24.5m, constituted by concrete beams and slabs and being currently used for pedestrian crossing. Initially, the Frequency Response Function (FRF) of the structure was obtained by impact modal hammer. After that, a vibrometer device based on Laser Doppler Vibrometry was used, in order to acquire the experimental modal data of the investigated footbridge. Then, these experimental results were calibrated with a developed three-dimensional numerical model that adopted the usual mesh refinement techniques present in finite element method simulations, based on the use of ANSYS program. Afterwards, a forced vibration analysis was performed on the structure, based on human-induced loads, considering two control groups: the first one is intended to excite the investigated footbridge to cause resonance motion with a controlled step frequency and the second one is related to freely random people crossing the footbridge as it occurs normally during its real life. Thus, the structural system dynamic response in terms of peak accelerations values were evaluated and compared to the limiting values proposed by several authors and design standards aiming to assess the vibration serviceability of the analysed pedestrian footbridge.

Tuesday, 20 October 2015, 11:15 – 12:45

Session T2-2

Room: Academy II

Chair: Eleni N. Chatzi, ETH Zürich, Switzerland

Experimental technology of operational pipeline condition monitoring

A. Mironov, P. Doronkin and A. Priklonsky

This work presents a summary of the research study of operational modal analysis (OMA) application for condition monitoring of operating pipelines. Special focus is on the topicality of OMA for definition of the dynamic features of the pipeline (frequencies and mode shapes) in operation. The research was conducted using two operating laboratory models imitated a part of the operating pipeline. The results of finite-element modelling, identification of pipe natural modes and its modification under the influence of virtual failure are discussed. The work considers the results of experimental research of dynamic behavior of the operating pipe models using one of OMA techniques and comparing dynamic properties with the modelled data. The study results demonstrate sensitivity of modal shape parameters to modification of operating pipeline technical state. It is resumed about ability of operating pipeline condition monitoring by measuring dynamic deformations of the operating pipe and OMA techniques application for dynamic properties extraction.

Vibration analysis based on surface acoustic wave sensors

A.P. Gnadinger

It is important to know, whether a civil engineering structure is safe or unsafe. One way to determine this is to measure vibrations at critical locations and feeding this data into an appropriate algorithm. Albido Corporation has developed wireless strain sensors based on surface acoustic wave (SAW) principles that are mainly employed on rotating structures and in harsh environments. Albido's sensors could also be used to measure vibrations in civil engineering structures. They are small (~1 x 3 mm), passive and inexpensive (< 1$ in volume). They are powered by the electromagnetic field emanating from the antenna of a Reader System, similar to an RFID. The Reader System is essentially a computer with special software and has signal processing capability. One Reader System can service a multitude of sensors. The Reader antenna has to be within the reading range of the sensor. If large distances are required, a small electronic component acting as a Reader System can be placed within the reading range of the sensor that receives the sensor signal, generates a radio signal and encodes the sensor information on the radio signal. Then, the final data processing centre can be placed anywhere.

Vibration testing and evaluation for source detection of bothersome structural vibrations

M.A. Pavelchak

Buildings are subjected to a myriad of vibration excitation sources including mechanical systems, human activity, vehicular traffic, and other environmental conditions. The characteristics (amplitude and frequency) of the excitation from these sources can vary significantly overtime as building use patterns change, systems age, and maintenance activities vary. Overtime many building owners/operators find themselves dealing with vibration complaints which arise unexpectedly and without obvious cause. The complexity of many modern facilities can make pinpointing the source of bothersome vibrations equivalent to finding a needle in a haystack. The objective of this paper is to explore the process of vibration source detection in complex existing facilities through three recent case studies. The vibration testing and evaluation methodologies utilized for source detection on these case studies is explored to highlight challenges faced on these types of projects. Each of the case studies involves existing buildings with many years of successful operation before bothersome vibration events were reported. The case studies presented, explore complaints related to sensitive medical equipment as well as human perception of vibrations.

Vibration immission forecast by means of train equivalent synthetic vibration experiments

P. Steinhauser and W. Steinhauser

Vibration abatement measures at a railway track require forecasts before the rails are put into place. Due to the multiple feedback system between train, track, geodynamics of the local underground and the dynamic behaviour of the neighbourhood buildings these prognoses become very elaborate. All the parameters of the dynamic system scatter extremely as the results from numerous investigations prove. This concerns vibration emission spectra, tunnel mobility, geodynamic vibration loss along the transfer through the underground as well as the natural frequencies from buildings and ceilings. Therefore experimental in-situ investigations are indispensable for trustworthy forecasts. In this paper the VibroScan method is presented, whose basic idea is to implement the principle of equivalence between the synthetic vibrations used for the experiments and train vibration emissions at the highest possible degree. This is focused on emission spectra, force of excitation, unsprung wheelset mass and axle load. The necessary experimental provisions are discussed and some examples of results are given like the protection of the Musikverein building in Vienna or the Sagrada Familia basilica in Barcelona against vibrations from tunnels in the immediate neighbourhood.

Tuesday, 20 October 2015, 14:15 – 15:00 | **Room: Academy I**
Keynote lecture | **Chair: Flavio Barbosa, Univ. Federal de Juiz de Fora, Brazil**

Dynamic properties of footbridges: influence of asphalt pavement and support conditions

Benedikt Weber

Empa, Structural Engineering Laboratory, Duebendorf, Switzerland

The most important parameters in the design of footbridges against vibration problems are the natural frequencies and damping ratios. Although determining these properties seems to be a simple standard task, calculated frequencies as well as estimated damping values are often not realistic if the influence of non-structural elements is not considered. In particular, the asphalt pavement and the supports can have a significant influence on the dynamic properties of footbridges. Including these effects is important for interpreting experimental results or for the design.

In this keynote paper we present results from dynamic experiments conducted on four footbridges in the last few years with the goal to analyse the influence of the asphalt temperature on the dynamic properties. To cover the full range of temperatures, tests were conducted on several days distributed over the seasons of the year. Along with the vibration tests, asphalt temperatures were measured with embedded thermo-elements.

The experiments show that both the natural frequencies and the damping ratios can change significantly with asphalt temperature. In the timber bridge shown in Figure 1, a variation in natural frequency of 25% has been observed between high and low asphalt temperatures. An additional damping of around 1% due to the asphalt pavement has been detected at intermediate temperatures.

Comparing the results from the four footbridges shows that the influence of the asphalt depends mainly on the position of the pavement relative to the neutral axis of the cross-section. However, other effects may play a role: (i) If the pavement is not fully bonded to the beam, the interface stiffness may reduce the effect. (ii) If the dynamic behaviour is not entirely governed by bending, e.g. in a cable-stayed bridge, the effect of asphalt is reduced. (iii) Short bridges might vibrate more like a plate than like a beam. In this case, the cross-section might not fully describe the dynamic behaviour.

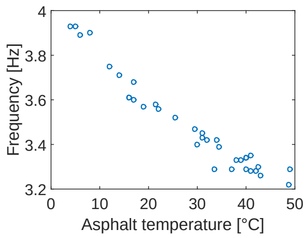


Figure 1: Timber footbridge and its fundamental frequency measured at different temperatures of the asphalt pavement.

While the influence of the asphalt pavement has been investigated systematically, other examples of non-structural effects have been observed, which are not less relevant but more difficult to predict. In a girder box steel bridge, the high friction in the bearings increased the expected frequency of 1.4 Hz to a critical value of 1.8 Hz. Luckily, the friction also increased the damping to almost 2%, preventing any vibration problems.

In a steel truss bridge, the frequency of the torsion mode was affected by the horizontal stiffness of the elastomer bearings. However, using the stiffness provided by the manufacturer, the torsion frequency predicted by a numerical model disagreed with the measurements. It turned out that the dynamic stiffness of the bearings for small deformations was about ten times higher than the static value provided by the manufacturer.

Tuesday, 20 October 2015, 15:00 – 16:15

Session T3-1

Room: Academy I

Chair: Alexandre Cury, Univ. Federal de Juiz de Fora, Brazil

Automated modal tracking and fatigue assessment of a wind turbine based on continuous dynamic monitoring

G. Oliveira, F. Magalhães, Á. Cunha and E. Caetano

Wind power is one of the most attractive alternatives to conventional energy solutions. With the development of the technology, higher and slender multi-MW wind turbine systems have been installed worldwide, both at onshore and offshore. Current wind turbines are large structures, prone to dynamic problems and fatigue wear. In that sense, monitoring systems developed to remotely assess the condition of these structures could be very useful to attest the real condition of wind turbines. This paper describes the implementation of a dynamic monitoring system in a 2.0 MW onshore wind turbine, developed by the Laboratory of Vibrations and Structural Monitoring (ViBest, www.fe.up.pt/vibest) of the University of Porto. The system is composed by two components aiming at the structural integrity and fatigue assessment. The first component enables the continuous tracking of modal characteristics of the wind turbine (natural frequency values, modal damping ratios and mode shapes) in order to detect abnormal deviations of these properties, which may be caused by the occurrence of structural damage. On the other hand, the second component allows the estimation of the remaining lifetime of the structure based on the analysis of the measured cycles of structural vibration. This strategy has already proven to be suitable for both in onshore and offshore locations. The first part of the paper introduces some results obtained with the continuous identification of the modal properties of the wind turbine. Some noticeable relationships between the modal properties and the operation/ environmental conditions are also shown. The second part of the paper illustrates the application of the fatigue monitoring system to real data collected. In addition, the virtual sensors methodology, aiming at estimating the acceleration at unmeasured locations of the structure, is introduced in order to optimize the layout of the dynamic monitoring system

The vibration based fatigue damage assessment of steel and steel fiber reinforced concrete (SFRC) composite girder

C. Xu, S. Fukada and H. Masuya

Steel-concrete composite girders, consisting of concrete slab, steel girder, and shear connectors, have been often applied in bridges and buildings. Since the live load accounts for a high percentage of the design load of composite bridges, the fatigue aspect cannot be disregarded. In particular, in the negative flexural region of a continuous composite girder bridge, fatigue tensile concrete cracks may easily occur, leading to safety and durability problems. The current fatigue damage assessment for composite girders is largely based on concrete strain values or crack features. Such methods are time consuming and the accuracy is not stable. Vibration-based fatigue damage assessment has been considered instead in this study. Particularly, the natural frequency, corresponding vibration mode etc were all observed through carrying out impact tests during the fatigue damage development. These observations were expected to indicate fatigue damage induced stiffness degradations and severe damage locations. A steel-steel fiber reinforced concrete (SFRC) composite girder was designed and tested. The reason of using steel fiber reinforced concrete was that it has been considered one of the ways dealing with concrete cracks in engineering practice. The composite girder was 3.3m long and 0.45m high. The steel girder was 0.35m high and the SFRC slab width was 0.6m. Static load, fatigue load and impact load were applied on the specimen sequentially with the goal to produce fatigue damage, deriving the vibration modes and corresponding frequencies. According to the test results, the concrete crack development and global stiffness degradation during the fatigue test were relatively slow due to the favourable performance of SFRC in tension. But on the other hand, the vibration characteristics varied significantly during the fatigue damage development. Such variations were found to have very close relationships with fatigue induced damages. Generally, the feasibility of executing fatigue damage assessment of composite bridge based on vibration method was confirmed.

Dynamic investigations of various civil engineering structures due to ambient and mining tremors

K. Kuzniar and T. Tatara

The paper presents examples of dynamic testing and the results for selected structures of different types. The study focused on showing the possibilities of research in situ dynamic structures for different dynamic excitation. They were gusts of wind, rhythmic swaying of people, vibrator Mark – 3 used in the exploration works, natural underground mining tremors and normal and emergency operation of lifting equipment in coal mines. The first part of the study deals with evaluation of dynamic characteristics of selected typical industrial facilities, such as the extraction steel tower, reinforced concrete tower skips. These structures are located in the coal mine area. The constructions of the test items are varied and complicated, which causes difficulties in the research in situ. In the investigation we used normal and emergency operation of lifting equipment, the effect of wind gusts and rhythmic man swaying. The results of experimental studies were the basis for the verification of dynamic models of these structures. The second part of the study involves the determination of the dynamic characteristics of tailing dam. In this case mining tremors were used as the sources of vibration excitations. By using natural vibration excitation source it was possible to determine the lowest frequency of free vibration of the tailing dam. The third part of the paper focuses on the results of measurements of mine-induced ground vibrations and vibrations of residential buildings of various types. Typical one-family masonry houses as well as 5 and 12 storey reinforced prefabricated buildings were examined. The studies were conducted to determine the transmission of free-field vibrations to the building foundations. According to the significant differences between the simultaneously measured ground and building foundation vibrations, results of experimental tests obtained by means of response spectra are essential for the proper adoption of kinematic loads for dynamic models of these structures.

Tuesday, 20 October 2015, 15:00 – 16:15
Session T3-2

Room: Academy II
Chair: Glauco Feltrin, Empa, Switzerland

Reliable overlapping control for civil structures

L. Bakule, M. Papík and B. Rehák

The article presents results of experimental analysis targeted to actuator and sensor failures in the overlapping decentralized LQG feedback-based structure to mitigate responses of an earthquake-excited 20-story building. The building structure belongs to the second generation of civil engineering benchmark models. It includes a complete physical description, a high-fidelity finite element model and a Matlab/Simulink simulation framework. The presented performance analysis is focused on sensor and actuator failures appearing in individual local loops within two overlapped subsystems of an in-plane (2D) structure under the four real world historical earthquake records. The benchmark evaluation criteria and dynamic responses are analyzed to assess the acceptable performance.

Fuzzy logic controller scheme for floor vibration control

D.S. Nyawako, P. Reynolds, R.L. Pimentel and E. Hudson

The design of civil engineering floors is increasingly being governed by their vibration serviceability performance. This trend is the result of advancements in design technologies offering designers greater flexibilities in realising more lightweight, longer span and more open-plan layouts. These floors are prone to excitation from human activities. The present research work looks at analytical studies of active vibration control on a case study floor prototype that has been specifically designed to be representative of a real office floor structure. Specifically, it looks at tuning fuzzy control gains with the aim of adapting them to measured structural responses under human excitation. Vibration mitigation performances are compared with those of a general velocity feedback controller, and these are found to be identical in these sets of studies. It is also found that slightly less control force is required for the fuzzy controller scheme at moderate to low response levels and as a result of the adaptive gain, at very low responses the control force is close to zero, which is a desirable control feature. There is also saturation in the peak gain with the fuzzy controller scheme, with this gain tending towards the optimal feedback gain of the direct velocity feedback (DVF) at high response levels for this fuzzy design.

Vibration mitigation of a bridge cable using a nonlinear energy sink: design and experiment

M. Weiss, B. Vaurigaud, A. T. Savadkoohi and C.-H. Lamarque

This work deals with the design and experiment of a cubic nonlinear energy sink (NES) for horizontal vibration mitigation of a bridge cable. Modal analysis of horizontal linear modes of the cable is experimentally performed using accelerometers and displacement sensors. A theoretical simplified 2-dof model of the coupled cable-NES system is used to analytically design the NES by mean of multi-time scale systems behaviours and detection its invariant manifold, equilibrium and singular points which stand for periodic and strongly modulated regimes, respectively. Numerical integration is used to confirm the efficiency of the designed NES for the system under step release excitation. Then, the prototype system is built using geometrical cubic nonlinearity as the potential of the NES. Efficiency of the prototype system for mitigation of horizontal vibrations of the cable under for step release and forced excitations is experimentally demonstrated.

Wednesday, 21 October 2015, 8:45 – 9:30 | **Room: Academy I**

Keynote lecture | **Chair: Carmelo Gentile, Politecnico di Milano, Italy**

Dynamics of railway bridges: analysis and verification by field tests

Andreas Andersson[1,2] and Raid Karoumi[1]

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[2]*The Swedish Transport Administration (Trafikverket), Sweden*

There is an increased demand on the railway sector and much resource is spent on increasing the capacity of the existing network as well as expanding and connecting new lines. According to the European Commission White Paper the following targets are stipulated; shift 30% of the road freight over 300 km to rail and waterborne transports, triple the length of the existing high-speed railway (HSR) by 2030 and complete a European HSR by 2050 and connect all core network airports to the rail network by 2050. To realise these ambitious goals, much effort must be spent on finding viable solutions, e.g. methods to prove that a larger share of the existing infrastructure can be upgraded to future demands and finding more cost and time efficient methods for building new railway infrastructure. There are about 300,000 railway bridges in Europe and an estimated 35% are older than 100 years. From a survey performed within the Sustainable Bridges project, better assessment tools and verification of dynamic amplification factors were mentioned among the top 10 priority researches.

In this paper, different aspects of railway bridge dynamics is presented, with an emphasis on Swedish conditions. Both theoretical and experimental cases are presented. Two larger theoretical studies on the dynamic assessment of railway bridges have been performed; a feasibility study to investigate if it is possible to upgrade more than 1,000 railway bridges on conventional lines to HSR and a performance check of 76 railway bridges along a newly built mixed train line with an allowable speed of 250 km/h. About 50% of the railway bridge stock in Sweden is designed as portal frame bridges, typically with a span of 2 – 15 m, although sometimes up to 25 m. Different approaches for structural models of portal frame bridges are illustrated in Figure 1. If the response is governed mainly by 2D bending, Figure 1a may give similar results as a 3D-model, Figure 1b. The support conditions are determined from a separate model, considering the walls, wing-walls and foundation stiffness. Theoretical studies have shown that short- and medium span bridges on elastic supports may give rise to excessive vibrations. An important factor for vibration mitigation is the soil-structure interaction (SSI), which in the simple approach may be approximated with a dashpot. Due to the dynamic properties of both the structure and the soil, significant frequency dependencies in both the stiffness and the damping may however need to be considered.

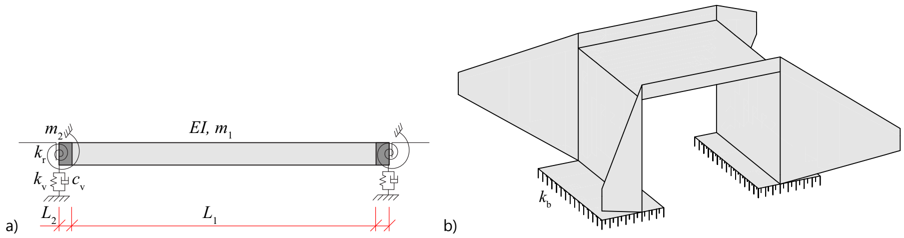

Figure 1. a) Simple 2D beam model for a portal frame bridge accounting for SSI, b) 3D model of a portal frame bridge.

Results from the theoretical assessment of 76 railway bridges on a newly built line in Sweden are presented. The design limit for vertical deck acceleration is 3.5 m/s2. In the first part of the analysis, models similar to Figure 1a was used. The results indicate potential problems for many of the portal frame bridges, partly due to conservative assumptions regarding the SSI. The simulations show a risk of resonance for some of the simply supported steel-concrete composite bridges, owing to a low natural frequency and a low mass. Large vibrations are also predicted for bridges with integrated back walls and large over-sail, due to the impact load when the train reach the tip of the cantilever edge.

Experimental testing has been performed on a three-span concrete slab bridge with large over-sail. The load consists of a recently developed hydraulic bridge exciter. The system has a capacity of 25 kN load amplitude in a frequency range of more than 50 Hz. From a first pilot test, the experimental frequency response function (FRF) shows reasonable similarity with a developed 3D-model. The model is used to simulate the dynamic response from passing trains, illustrating the potential vibration mitigation from SSI.

Wednesday, 21 October 2015, 9:30 – 10:45
Session W1-1

Room: Academy I
Chair: Benedikt Weber, Empa, Switzerland

Quantification of human-structure interaction

C. Caprani, J. Qu, S. Živanović, N. Evans and E. Ahmadi

In lightweight structural systems there is increasing evidence that the presence of humans influences the dynamics characteristics of the system. In the past, most effort on determining the footfall-induced vertical force to the walking surface has been conducted using rigid or non-flexible surfaces such as treadmills. However, should the walking surface be vibrating, the characteristics of human walking could change to maximize comfort. This interaction between the structure and human may account for the discrepancy between the levels of vibration predicted by theory and those observed in practice. Indeed, many design rules can be seen to be conservative, perhaps partly because knowledge of this human-structure interaction is limited. This work aims to address this problem by quantifying the magnitude of human-structure interaction through a comprehensive experimental programme. Novel experimental techniques are used to measure the human-imparted force on the walking surface. Both rigid and flexible (vibrating) surfaces are used, and we measure the imparted vibration response on a lively footbridge (the Warwick Bridge) which acts as the flexible surface. A range of test subjects is considered, walking at a range of pacing frequencies. Comparison is made between a notional vibration response from the footfall force imparted to the rigid surface and the actual vibration response caused by the footfall force imparted to the flexible surface. Key aspects of the experimental regime are also explained. Finally, some comparisons are made using footfall force models from the literature. It is concluded that human-structure interaction is a key phenomenon that should be taken into account in the design and assessment of vibration-sensitive structures.

Evaluation of human-induced vibration of continuous footbridges

A. El Robaa, S. Gaawan and C. Malek

With the development of construction materials and the introduction of high strength steel and concrete, the human-induced vibration became a dominant criterion for the design of pedestrian bridges. Currently, longer spans and lightweight bridges have been comprised in most of design trends. This leads to lower the natural frequencies of the system which have a great effect on the dynamic performance of bridges subjected to human activities. Although the design of steel footbridges could reach the optimum level of design in terms of strength criterion, it might not reach the acceptance level for vibration condition. This will enforce the designer to choose section profiles with higher inertia to enhance stiffness of the whole system. This paper presents an overall assessment for floor vibration problem due to pedestrian induced vertical forces on continuous composite footbridges. The footfall method presented by concrete centre "CCIP-016" is adopted in this study to evaluate the response factor and acceleration of pedestrian bridges using a FEA software package "Robot Structural Analysis".

Field investigations on the lateral vibration features of prestressed concrete stress ribbon footbridges

S. Fukada, C. Xu, T. Yoshikawa and M. Tsunomoto

The prestressed concrete (PC) stress ribbon footbridge is a type of suspension bridge without towers, which has been applied in Japan and all over the world for years in light of its low construction cost and aesthetic merit. It generally consists of the precast concrete slabs with embedded cables. However, the walking-induced lateral vibration trouble of the Millennium Bridge in London in 2000 gave a lesson to the engineers that the lateral vibration feature must be taken into consideration for the footbridge vibration evaluation. Unfortunately, the lateral vibration investigations on the current existing footbridges in Japan and around the world are much less than the vertical investigations, resulting in the potential safety troubles. In this sense, the field investigations on the lateral vibration features of 14 pre-stressed concrete stress ribbon footbridge in Japan was carried out by artificial impact and damping free vibration tests. The bridge span length ranged from 45.0m to 147.6m, and the ratio of span length to sag ranged from 30.0 to 42.2. There were 12 velocity sensors used in each of the bridge field investigations for deriving the bridge vibration modes. They were distributed at the locations where the distances to the span end were L/8, 2L/8, 3L/8, 4L/8, 5L/8, 6L/8 and 7L/8, respectively. According to the investigations, the larger the bridge span, the lower the frequencies of lateral-related vibration modes. The investigated bridges with span length exceeding 80m were found to be with walking-induced lateral vibration frequencies in the range from 0.5Hz to 1.2Hz. But this is the lateral vibration frequency range that must be avoided based on the current vibration codes such as Hivoss guidelines. In other words, there were nearly a half of the investigated bridges found to be with the lateral walking-induced vibration problems. In addition, based on the damping-free vibration field tests, there was a tendency toward the damping constant degradation when bridge span became larger. On the other hand, the numerical simulation of several vibration tests on bridges was carried out. The stress ribbon decks and lateral members were modeled as beam elements and rigid elements, respectively. The stiffness of embedded tendons were added to the beam elements. The analyzed lateral vibration frequencies and modes were consistent with the corresponding results derived from field investigations. This confirmed the reliability of the field investigations and the feasibility of applying parametric analysis to explore lateral vibration suppression method in the next step.

Wednesday, 21 October 2015, 11:15 – 12:45
Session W2-1
Room: Academy I
Chair: Stana Živanović, Univ. of Warwick, United Kingdom

Dynamic tests on a concrete slab with a tuned mass damper

J.E.C. Carmona, S.M. Avila and G.N. Doz

Nowadays, structures became more slender and flexible due to lighter materials with great resistance, compared to traditional materials used in construction. This fact provides to structural systems with low natural frequencies. High amplitude vibrations can be experienced, when the structures are subjected to people walking, running, jumping, dancing, activities that are characterized by periodical low frequency forces. Various solutions can be taken, such as techniques to stiffen all the structure, which can result a non-economical solution and not practical. Other alternative that can be more economical and executable is to install tuned mass dampers (TMD) at the building structure, that vibrate out of phase with the main system, transferring the mechanical energy to the additional mass. In this work, excessive vibrations in concrete slabs are studied through testing a dynamic platform very flexible where it is installed a TMD. The tests simulate human activities such as walking, jumping or dancing. Vibrations amplitudes of the platform are compared with and without TMD installation, finding a good reduction on these amplitudes with this structural control device. The TMD designed has a dry friction mechanism to reduce the response of the additional mass, controlling excessive vibration caused by human activities in building floors.

Dynamic properties comparisons between experimental measurements and nondeterministic numerical models of viscoelastic sandwich beams

W.N. Felippe Filho and F. Barbosa

In order to design viscoelastic sandwich structures used as passive damping treatment, many aspects should be considered. In all methods available in the literature to model Viscoelastic Materials (VEM) a crucial step is the determination of the complex modulus, usually obtained by curve fitting experimental results. Considering that dispersions are inherent to experimental tests and also those small variations in the fitted parameters lead to considerable changes on the dynamic behavior of VEMs hence a nondeterministic model seems to be more suitable than the usual deterministic ones. In that way, starting from dynamic properties of a VEM, a nondeterministic numerical model, which takes into account incertitudes in the VEM curve fitting procedure, is proposed. This model was used to evaluate the behavior of sandwich structures, showing the advantages and disadvantages of the presented methodology, comparing damping results of experimental tests with the ones extracted from the proposed nondeterministic numerical GHM based model, in order to establish a method to support viscoelastic sandwich beams design.

Application of concrete segment panels for reduction of torsional vibration responses of girder bridges

J.-W. Kwark, J.-Y. Kang, S.-Y. Park and K.-T. Kim

The dynamic flexural behaviour of the railway bridge is influenced by its torsional behaviour. Especially, in the case of girder railway bridges, the dynamic response tends to amplify when the natural frequency in flexure (1st vibration mode) is close to that in torsion (2nd vibration mode). In order to prevent such situation, it is necessary to adopt a flexural-to-torsional natural frequency ratio larger than 120%. This study proposes a solution shifting the natural frequency in torsion to high frequency range and restraining torsion by installing concrete panels on the bottom flange of the girder so as to prevent the superposition of the responses in the girder bridge. The applicability of this solution is examined by finite element analysis of the shift of the torsional natural frequency and change in the dynamic response according to the installation of the concrete panels. The analytical results for a 30 m-span girder railway bridge indicate that installing the concrete panels increases the natural frequency in torsion by restraining the torsional behaviour and reduces also the overall dynamic response. It is seen that the installation of 100 mm-thick concrete panels along a section of 4 m at both extremities of the girder can reduce the dynamic response by more than 30%.

Vibration isolation measures due to the high sensitive linear accelerator at the Paul Scherrer Institute

P. Trombik, P. Fleischer and M.F. Vassiliou

The new 735m long linear accelerator “SwissFEL” at the Paul Scherrer Institute (PSI) in Würenlingen is extremely sensitive against vibrations coming from surrounding equipment (pumps, ventilators, transformers, etc.). The manufacturer’s vibration limit for this linear accelerator is 0.1µm displacement amplitude. Therefore, all vibration sources must strictly be isolated to the highest-possible degree from the rest of the structure. This paper discusses the vibration situation in general for this unique construction (ground vibrations, vibration propagations / structural amplifications, vibration limits, etc.) and as a case study the isolation of a pump located in the building. Steel springs were used and it was achieved to reduce the vibration transmitted to the floor by more than 99%, to a level where the coherent component of the motion recorded on the floor next to the linear accelerator is non-measurable / below the ground motions. The measurements were found to be in good accordance with the FEM model used.

Wednesday, 21 October 2015, 11:15 – 12:45
Session W2-2

Room: Academy II
Chair: Joel P. Conte, Univ. of California, San Diego, USA

Theoretical and experimental study of coupled rocking-swivelling model of guyed mast shaft

S. Urushadze, M. Pirner and O. Fischer

Systematic monitoring of torsion (swivelling) of guyed mast shafts has been performed in ITAM since 2005. The occurrence of this phenomenon is conditioned by the fact that the guy ropes are attached to the surface of the shaft, i.e. out of its axis. The simple static calculation model serves for making the proof of the occurrence of the moment, affecting the shaft, which is guyed by three ropes. The exact theoretical solution of the real phenomenon assumes the introduction of dynamics of guy ropes, which vibrate in 3D shapes during the shaft's movement along the orbit and it´s torsion (swivelling). As well as a detailed determination of the aerodynamic characteristic of the shaft cross-section with respect to the conditions of aerodynamic instability. In more detail and more stable aerodynamic conditions was the phenomenon of swivelling of the mast shaft examined on a simple model. The shaft was a tube of hardened PVC, of an outer diameter of 75 mm, supported by a point at the bottom guyed by three wires in one level. The out of axis was changed for its influence estimation. The flexural rigidity of the shaft is not modelled; the bending is substituted by the tilting. That is why there are no higher shapes of tilting and the orbit is always close to ellipse. The torsion was verified in a wind tunnel. The experiments have been performed in the new aerodynamic tunnel (ITAM – Telč). Wind tunnel section size enabled experiment with model shaft up to 1500 mm high, anchored by three ropes at a height of 1000 mm. The top end of the shaft was equipped with a horizontal arm with two accelerometers attached on its ends; the distance between the accelerometers is 380 mm. Accelerometers 1 and 2 sense the motion in the direction perpendicular to the horizontal arm. Besides the two accelerometers on the horizontal arm there is also the third accelerometer at the upper end of the shaft, which senses the motions perpendicular to the direction of the above pair of accelerometers. The mast model was adjusted within the admissible limits by means of stressing of the wires and increasing of the mass concentrated on the top of the shaft.

Experimental and numerical response of rigid slender blocks with geometrical defects under seismic excitation

C. Mathey, C. Feau, I. Politopoulos, D. Clair, L. Baillet and M. Fogli

The present work investigates on the influence of small geometrical defects on the behavior of slender rigid blocks. A comprehensive experimental campaign was carried out on one of the shake tables of CEA/Saclay in France. The tested model was a massive steel block with standard manufacturing quality. Release, free oscillations tests as well as shake table tests revealed a non-negligible out-of-plane motion even in the case of apparently plane initial conditions or excitations. This motion exhibits a highly reproducible part for a short duration that was used to calibrate a numerical geometrically asymmetrical model. The stability of this model when subjected to 2000 artificial seismic horizontal bidirectional signals was compared to the stability of a symmetrical one. This study showed that the geometrical imperfections slightly increase the rocking and overturning probabilities for earthquake signals in a narrow range of peak ground acceleration.

The dynamic properties of the bridge deck model reinforced with FRP bars

B. Markiewicz, K. Pereta and G. Piatkowski

Significant application of composites can be observed in numerous fields over the last decades. Composite materials mainly used in the aeronautics industry are gaining more and more application in various areas such as the construction of bridges. The article presents a set of dynamic researches carried out on a plate made of lightweight concrete reinforced with composite rods. The tested plate with dimensions 514 x 190 x 18 cm was a model of the actual bridge deck. A multichannel signal recorder with specialized software was used for performing the measurements and to estimate modal parameters of the plate. Dynamic response of the plate on a modal hammer impact was measured with numerous of piezoelectric acceleration sensors. A range of FEM models was created, started with 1-D beam model. Next, 2-D plate and 3-D volume, more complex models were developed. Only in the 3-D model the composite rods were modelled. The basic frequencies and mode shapes obtained for physical model were compared with those for numerical models. There were significant differences. The conducted analysis indicated more complicated than theoretical boundary conditions of the tested plate.

Vibration analysis of a residential building

R.A.C. Sampaio and R.M. de Souza

The aim of this paper is to present the results of a study regarding vibration problems in a 17 storey residential building during pile driving in its vicinity. The structural design of the building was checked according to the Brazilian standards NBR6118 and NBR6123, and using commercial finite element software. An experimental analysis was also carried out using low frequency piezo-accelerometers attached to the building structure. Structure vibrations were recorded under ambient conditions. Four monitoring tests were performed on different days. The objective of the first monitoring test was an experimental modal analysis. To obtain de modal parameters, data was processed in the commercial software ARTEMIS employing two methods: the Stochastic Subspace Identification and the Frequency Domain Decomposition. Human comfort was investigated considering the International Standard ISO 2631. The Portuguese standard, NP2074, was also used as a reference, since it aims to limit the adverse effects of vibrations in structures caused by pile driving in the vicinity of the structure. The carried out experimental tests have shown that, according to ISO2301, the measure vibration levels are above the acceptance limits. However, velocity peaks are below the limits established by NP2074. It was concluded that, although the structure has adequate capacity to resist internal forces according to normative criteria, it has low horizontal stiffness, which could be verified by observing the vibration frequencies and mode shapes obtained with the finite element models, and its similarity with the experimental results. Thus, the analyses indicate the occurrence of discomfort by the residents.