Aerodynamics and rain rivulet suppression of bridge cables with concave fillets

In this paper, the aerodynamic performance of two new cable surfaces with concave fillets (strakes) is examined and compared to plain, dimpled and helically filleted surfaces. To this end, an extensive wind-tunnel campaign was undertaken. Different samples with different concave fillet heights for both new surfaces were tested and compared to traditional surfaces in terms of aerodynamic forces (i.e. drag and lift reduction) and rain-rivulet suppression. Furthermore, flow visualization tests were performed to investigate the flow separation mechanism induced by the presence of the concave fillet and its relation to the aerodynamic forces. Both new cable surfaces outperformed the traditional surfaces in terms of rain-rivulet suppression thanks to the ability of the concave shape of the fillet to act as a ramp for the incoming rain-rivulet. Furthermore, both new surfaces with the lowest tested fillet height were found to have drag coefficients in the supercritical Reynolds range that compare favorably to existing cable surfaces, with an early suppression of vortex shedding.

Scenario Based Approach for Load Identification

In output only analysis the load identification has been a puzzle for several years. Different techniques have been purposed to cope with the inversion problem that lies within this field. However it has been shown, that most methods struggle to obtain robust and consistent results in cases of modal truncation and noise contaminated signals. In the light of these challenges, a scenario based method is proposed. This approach utilizes model updating along with mode shape expansion to obtain a reliable numerical model of the given structure. Then, by evaluating a series of rational load scenarios, it is possible to obtain a reasonable input identification – both the spatial distribution and the temporal variation of the load. The method is demonstrated numerically and experimentally.
A smart base restraint for wind turbines to mitigate undesired effects due to structural vibrations

Concerns in the last decades of the negative impact of the use of fossil fuels on the environment has lead to a boom in the production of wind turbines. To take advantage of the smoother stronger winds at height, wind turbine heights are progressively increasing. This has led to an increased demand to control tower forces. The application of a semi-active (SA) control system is herein proposed and discussed. Its aim is to limit bending moment demand at the base of a wind turbine by relaxing the base restraint of the turbine's tower, without increasing the top displacement. This is done thanks to the sharp increase of the dissipated energy in selected intervals of time and an adaptive change in tower dynamic properties. This SA control system reproduces a variable restraint at the base that changes in real time its mechanical properties according to the instantaneous response of the turbine's tower. This smart restraint is made of a central smooth hinge, elastic springs and SA magnetorheological dampers driven by a control algorithm properly designed for the specific application. A commercial 105 m tall wind turbine has been assumed as a case study. Several numerical simulations have been performed with reference to an extreme load, aimed at establishing a procedure for the optimal calibration of the control algorithm according to the specific case, finally proving the actual potential of the proposed control technique in reducing the structural demand with respect to the “fixed base” structure.

Biomechanically Excited SMD Model of a Walking Pedestrian

Through their biomechanical properties, pedestrians interact with the structures they occupy. Although this interaction has been recognized by researchers, pedestrians' biomechanical properties have not been fully addressed. In this paper, a spring-mass-damper (SMD) system, with a pair of biomechanical forces, was used to model a pedestrian for application in vertical human-structure interaction (HSI). Tests were undertaken in a gait laboratory, where a three-dimensional motion-capture system was used to record a pedestrian's walking motions at various frequencies. The motion-capture system produced the pedestrian's center of mass (COM) trajectories from the captured motion markers. The vertical COM trajectory was approximated to be the pedestrian SMD dynamic responses under the excitation of biomechanical forces. SMD model parameters of a pedestrian for a specific walking frequency were estimated from a known walking frequency and the pedestrian's weight, assuming that pedestrians always walk in displacement resonance and retain a constant damping ratio of 0.3. Thus, biomechanical forces were extracted using the measured SMD dynamic responses and the estimated SMD parameters. Extracted biomechanical forces from all test trials were expressed with third-order Fourier series. It was found that the amplitude of the first-order biomechanical forces changed with the pacing frequency and that it fit a linear model. Amplitudes of the second- and third-order biomechanical forces were found to be scattered and not closely related to walking frequency. A generalized extreme value distribution was fit to each of the amplitudes. Phases in the model for biomechanical forces were not related to pacing frequency, and a mean value of the phases is proposed.
Comparative analysis of bridge cables with concave fillets

In this paper the aerodynamic performance of two new cable surfaces with concave fillets are examined and compared to cables with traditional helically filleted, plain and pattern indented surfaces. To this end, an extensive wind-tunnel campaign was undertaken to measure the aerodynamic static force coefficients up to the super-critical Reynolds number range and rain-rivulet suppression ability. Flow visualizations tests were performed to better understand the structure and development of the wake. Both innovations outperform traditional surfaces in terms of rain-rivulet suppression thanks to the ability of the concave shaped fillet to act as a ramp for the incoming rain-rivulet. Furthermore both innovations are able to suppress vortex shedding at low Reynolds numbers, in contrast to the other cable surfaces tested. Moreover the innovation with the staggered surface shows an early reduction of the drag force while maintaining a zero lift up to the super-critical range.

Design and calibration of a semi-active control logic to mitigate structural vibrations in wind turbines

The design of a semi-active (SA) control system addressed to mitigate wind induced structural demand to high wind turbine towers is discussed herein. Actually, the remarkable growth in height of wind turbines in the last decades, for a higher production of electricity, makes this issue pressing than ever. The main objective is limiting bending moment demand by relaxing the base restraint, without increasing the top displacement, so reducing the incidence of harmful "p-delta" effects. A variable restraint at the base, able to modify in real time its mechanical properties according to the instantaneous response of the tower, is proposed. It is made of a smooth hinge with additional elastic stiffness and variable damping respectively given by springs and SA magnetorheological (MR) dampers installed in parallel. The idea has been physically realized at the Denmark Technical University where a 1/20 scale model of a real, one hundred meters tall wind turbine has been assumed as case study for shaking table tests. A special control algorithm has been purposely designed to drive MR dampers. Starting from the results of preliminary laboratory tests, a finite element model of such structure has been calibrated so as to develop several numerical simulations addressed to calibrate the controller, i.e., to achieve as much as possible different, even conflicting, structural goals. The results are definitely encouraging, since the best configuration of the controller leaded to about 80% of reduction of base stress, as well as to about 30% of reduction of top displacement in respect to the fixed base case.
Optimization of bridge cables with concave fillets

In this paper the aerodynamic performance of new cable surfaces with concave fillet are examined and compared to plain, dimpled and helically filleted surfaces. To this end, an extensive wind-tunnel campaign was undertaken. Preliminary flow visualizations tests and static tests were performed to better understand the structure and development of the wake and the related aerodynamic forces. Subsequent improvements in design were focused on drag reduction and rain rivulet suppression. For this purpose a number of samples with different concave fillet’s height were tested in static condition to estimate the aerodynamic forces. Both new cable surfaces outperform traditional surfaces in terms of rain-rivulet suppression thanks to the ability of the concave shape of the fillet to act as a ramp for the incoming rain-rivulet. Furthermore, both improved innovations with lowest height of the concave fillet show optimal drag coefficients in the supercritical Reynolds range and an early suppression of vortex shedding formation.

Real-time monitoring and structural control of a wind turbine using a rocking system

The design of a semi-active (SA) control system to mitigate wind induced structural demand to high wind turbine towers is discussed herein. A variable restraint at the base, able to modify in real time its mechanical properties according to the instantaneous response of the tower, is proposed. A special control algorithm has been properly designed to drive MR dampers. It requires the tower is equipped with sensors for measurement of displacements and stresses. The real-time monitoring of the tower response is needed in order to make the SA system works in the sense of mitigating the structural demand against wind gust. A finite element model of a wind turbine model has been adopted to perform several numerical simulations. On the basis of these results, the optimal calibration of the controller has been found as the one allows to
achieve different and conflicting, structural goals.

**Structural health monitoring approach for detecting ice accretion on bridge cables using the autoregressive model**

Ice accretion on cables of bridge structures poses serious risk to the structure as well as to vehicular traffic when the ice falls onto the road. Detection of ice formation, quantification of the amount of ice accumulated, and prediction of iceloads will increase the safety and serviceability of the structure. In this paper, an ice accretion detection algorithm is presented based on the Continuous Wavelet Transform (CWT). In the proposed algorithm, the acceleration signals obtained from bridge cables are transformed using wavelet method. The damage sensitive features (DSFs) are defined as a function of the wavelet energy at specific wavelet scales. It is found that as ice accretes on the cables, the mass of cable increases, thus changing the wavelet energies. Hence, the DSFs can be used to track the change of cables mass. To validate the proposed algorithm, we use the data collected from a laboratory experiment conducted at the Technical University of Denmark (DTU). In this experiment, a cable was placed in a wind tunnel as ice volume grew progressively. Several accelerometers were installed at various locations along the testing cable to collect vibration signals.

**Structural Health Monitoring approach for detecting ice accretion on bridge cable using the Haar Wavelet Transform**

Ice accretion on cables of bridge structures poses serious risk to the structure as well as to vehicular traffic when the ice falls onto the road. Detection of ice formation, quantification of the amount of ice accumulated, and prediction of iceloads will increase the safety and serviceability of the structure. In this paper, an ice accretion detection algorithm is presented based on the Continuous Wavelet Transform (CWT). In the proposed algorithm, the acceleration signals obtained from bridge cables are transformed using wavelet method. The damage sensitive features (DSFs) are defined as a function of the wavelet energy at specific wavelet scales. It is found that as ice accretes on the cables, the mass of cable increases, thus changing the wavelet energies. Hence, the DSFs can be used to track the change of cables mass. To validate the proposed algorithm, we use the data collected from a laboratory experiment conducted at the Technical University of Denmark (DTU). In this experiment, a cable was placed in a wind tunnel as ice volume grew progressively. Several accelerometers were installed at various locations along the testing cable to collect vibration signals.
Wind turbines and seismic hazard: a state-of-the-art review

Wind energy is a rapidly growing field of renewable energy, and as such, intensive scientific and societal interest has been already attracted. Research on wind turbine structures has been mostly focused on the structural analysis, design and/or assessment of wind turbines mainly against normal (environmental) exposures while, so far, only marginal attention has been spent on considering extreme natural hazards that threaten the reliability of the lifetime-oriented wind turbine’s performance. Especially, recent installations of numerous wind turbines in earthquake prone areas worldwide (e.g., China, USA, India, Southern Europe and East Asia) highlight the necessity for thorough consideration of the seismic implications on these energy harnessing systems. Along these lines, this state-of-the-art paper presents a comparative survey of the published research relevant to the seismic analysis, design and assessment of wind turbines. Based on numerical simulation, either deterministic or probabilistic approaches are reviewed, because they have been adopted to investigate the sensitivity of wind turbines’ structural capacity and reliability in earthquake-induced loading. The relevance of seismic hazard for wind turbines is further enlightened by available experimental studies, being also comprehensively reported through this paper. The main contribution of the study presented herein is to identify the key factors for wind turbines’ seismic performance, while important milestones for ongoing and future advancement are emphasized.

General information
Publication status: Published
Organisations: Department of Civil Engineering, Section for Structural Engineering
Contributors: Katsanos, E., Thöns, S., Georgakis, C. T.
Pages: 2113-2133
Publication date: 2016
Peer-reviewed: Yes

Publication information
Journal: Wind Energy
Volume: 19
Issue number: 11
ISSN (Print): 1095-4244
Ratings:
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.37 SJR 1.079 SNIP 2.316
Web of Science (2016): Impact factor 2.725
Web of Science (2016): Indexed yes
Original language: English
Keywords: Wind turbines, Seismic loading, Earthquake strong ground motions, Multi-hazard environment, Dynamic analysis, Structural response, Soil-structure interaction
Electronic versions:
Katsanos_et_al_2016.pdf
DOIs:
10.1002/we.1968
Source: FindIt
Source-ID: 2292354495
Research output: Contribution to journal › Journal article – Annual report year: 2016 › Research › peer-review

Aerodynamics of bridge hangers in smooth and turbulent flow and implications on aeroelastic stability

The aerodynamics of circular cylinders featuring geometric imperfections, such as bridge cables, has received much attention in recent years due to the recognition that such imperfections can be the cause of large amplitude vibrations. Bridge cables are usually made of strands or wires protected by an extruded High Density PolyEthylene (HDPE) circular sheath [1]. In the last 20 years, several bridge cable manufacturers have introduced surface modifications on HDPE sheath in order to reduce the drag and to ensure the aerodynamic stability in all climatic conditions. In the case of plain HDPE sheaths, although manufacturers put in place all efforts to obtain smooth, perfectly circular sections, superficial irregularities such as roughness, labeling and ovalling make the aerodynamic behaviour deviate from that of perfect circular cylinder. The imperfections are the result of the manufacturing process, of mechanical damage occurring during transport and installation, as well as of the ageing process due to the exposure to environmental factors. Few experimental works are already available dealing with the effects of imperfections on the aerodynamics of bridge cables. For example, Matteoni and Georgakis and Larose et al. [2,3] confirming previous research showed that the appearance of a negative pressure bubble on one side of a real HDPE tube at the critical Reynolds number range leads to a rapid drop in the drag coefficient and the appearance of a non negligible mean lift force. Moreover, Matteoni and Georgakis, measuring roughness and shape deviation of the wind tunnel model, justified the measured aerodynamic coefficients. Flamand et al.
[4], using the Proper Orthogonal Decomposition (POD), measured the spatial and temporal correlation of the pressure pattern along the HDPE tube with surface and section irregularities, to characterise a bi-stable behaviour occurring at the critical Reynolds number regime; they showed that only three modes are sufficient to faithfully represent the fluctuation of the pressure field around the cable. Matteoni and Georgakis [5] studied the wind induced response of a full scale yawed bridge cable section model, for varying Reynolds numbers and wind angles-of-attack, using passive dynamic wind tunnel tests. They demonstrated that the in-plane aerodynamic damping of a bridge cable section and the overall dynamic response are strongly affected by changes in the angle of attack. This result is in agreement with the prediction of the quasi-steady theory using the result of static tests, although it was not possible to directly compare the regions of instability based on the static and passive dynamic tests. However, although many authors demonstrated the effects of superficial and sectional imperfection on aerodynamics, little attention has been paid to the refined measurement of aerodynamic data of a real cable and to their use in quasi-steady stability criteria. The purpose of the research herewith is to investigate the aerodynamics of a plain bridge hanger in smooth and turbulent flow and to evaluate the prediction of aerodynamic stability using the different models in literature, correlating these results with the measured imperfections of the tested cable.

Effects of ice accretion on the aerodynamics of bridge cables
Undesirable wind induced vibrations of bridge cables can occur when atmospheric conditions are such to generate ice accretion. This paper contains the results of an extensive investigation of the effects of ice accretion due to in-cloud icing, on the aerodynamic characteristics of bridge hangers and stay cables. The aim of this paper is twofold; first, it was investigated the ice accretion process and the final shape of the ice accreted; then the aerodynamics of the ice accreted bridge cables was characterized, and related to the ice shape. Different climatic conditions, i.e. combinations of temperature, wind speed and yaw angle of accretion, were reproduced in a climatic wind tunnel, giving rise to different types of accretion. These were chosen such to generate the most common natural ice formations expected to produce bridge cable vibrations. A description of the geometric characteristics of the ice accretions is given in the paper. Only for the bridge hanger case, a short description of the evolution of the ice accretions is given. The aerodynamic force coefficients were then measured with varying yaw angle, angle of attack and wind speed, and are presented and discussed in the paper; these are found to be significantly affected by the characteristics of the ice accretion.
Effects of surface roughness and cross-sectional distortion on the wind-induced response of bridge cables in dry conditions

Theoretical and experimental investigations to date have assumed that bridge stay cables can be modelled as ideal circular cylinders and that their aerodynamic coefficients are invariant with wind angle-of-attack. On the other hand it has been demonstrated that bridge cables are characterised by local alterations of their inherent surface roughness and shape. Small deviations from ideal circularity result in significant changes in the static drag and lift coefficients with Reynolds number. The present study focuses on the wind-induced response of a full-scale yawed bridge cable section model, for varying Reynolds numbers and wind angles-of-attack. Using passive-dynamic wind tunnel tests, it is shown that the in-plane aerodynamic damping of a bridge cable section, and the overall dynamic response, is strongly affected by changes in the wind angle-of-attack. Using the drag and lift coefficients, determined in static conditions for an identical cable model as the one used for passive-dynamic tests, the in-plane aerodynamic damping is evaluated by employing a one-degree-of-freedom (1 DOF) quasi-steady analytical model. Similarly, it is shown that regions of instability associated with the occurrence of negative aerodynamic damping are strongly dependent on the wind angle-of-attack.

Evaluation of Damping Using Frequency Domain Operational Modal Analysis Techniques

Operational Modal Analysis (OMA) techniques provide in most cases reasonably accurate estimates of structural frequencies and mode shapes. In contrast though, they are known to often produce uncertain structural damping estimates, which is mainly due to inherent random and/or bias errors. In this paper a comparison is made of the effectiveness of two existing OMA techniques in providing accurate damping estimates for random stationary loading, varying levels of signal noise, number of added measurement channels and level of structural damping. The investigation is focusing on the two frequency domain techniques, the Frequency Domain Decomposition (FDD) and the Frequency Domain Polyreference (FDPR). The response of a two degree-of-freedom (2DOF) system is numerically established with specified modal parameters subjected to white noise loading. The system identification is evaluated with well separated and closely spaced modes. Finally, the results of the numerical study are presented, in which the error of the structural damping estimates obtained by each OMA technique is shown for a range of damping levels. From this, it is clear that there are notable differences in accuracy between the different techniques.
Fretting fatigue behavior of high-strength steel monostrands under bending load

In this paper, the fretting fatigue behavior of pretensioned high-strength steel monostrands is investigated. To measure the local deformations on the strands, a novel method based on the digital image correlation (DIC) technique was used to quantify the relative movement between individual wires along the length of the monostrand. Information about the monostrand bending stiffness and the extent of relative displacement between core and outer wires of a monostrand undergoing flexural deformations is provided. From the series of dynamic fatigue tests, a fretting fatigue spectrum is derived and compared with the localized bending fatigue spectrum. The presented spectra can be used for the estimation of monostrand bending fatigue life. The results presented herein form the basis for the development of a fretting failure criterion for monostrand cables experiencing transverse displacements and are of special interest for the fatigue analysis of modern stay cable assemblies where fretting constitutes a major mechanism of the fatigue life reduction.
**Preliminary evaluation of two new cable surface innovations**

In this paper, the aerodynamic performance of two innovative bridge cable surfaces with concave fillets are examined and compared with traditional helical fillets. To this end, an extensive wind-tunnel test campaign was undertaken to measure the aerodynamic static force coefficients up to a Reynolds number of 3.2 x 10^5. The tests confirmed the results obtained from the preliminary tests performed by Kleissl and Georgakis (2013) on the prototype cable surfaces with the concave fillets. Despite a more than 100% increase of the fillet height compared to a traditional helical fillet profile, the static force coefficients are the same as that of a traditional helical fillet model at high Reynolds numbers. It is hypothesized that this is due to the ability of the concave shape of the fillet to enhance vorticity. Furthermore, both innovations are able to suppress vortex shedding formation at low Reynolds numbers, leading to a smooth and prolonged transition from the subcritical to the postcritical Reynolds number range.

**General information**
Publication status: Published
Organisations: Department of Civil Engineering, Section for Structural Engineering, FORCE Technology, VSL International Ltd.
Contributors: Burlina, C., Georgakis, C. T., Larsen, S., Egger, P.
Number of pages: 7
Publication date: 2015

**Host publication information**
Title of host publication: Proceedings of the 14th International Conference on Wind Engineering
Electronic versions:
ICWE14_ID02209.pdf
Source: PublicationPreSubmission
Source-ID: 115704837
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2015 › Research › peer-review

**Probabilistic Assessment of the Occurrence and Duration of Ice Accretion on Cables**
This paper presents an operational framework for assessing the probability of occurrence of in-cloud and precipitation icing and its duration. The framework utilizes the features of the Bayesian Probabilistic Networks. and its performance is illustrated through a case study of the cable-stayed Oresund Bridge. The Bayesian Probabilistic Network model used for the estimation of the occurrence and duration probabilities is studied and it is found to be robust with respect to changes in the choice of distribution types used to model the meteorological variables that influence the two icing mechanisms and their duration. The model is found to be more sensitive to changes in the discretization levels of the input variables. Finally, it is shown how forecasting of the meteorological variables, that is the probabilities of the occurrence of ice accretion and its duration, can be used to update the model. The updated probabilities can be used as a decision support tool for the management of risk and safety with respect to falling ice.

**General information**
Publication status: Published
Organisations: Department of Civil Engineering, Section for Structural Engineering
Contributors: Roldsgaard, J. H., Georgakis, C. T., Faber, M. H.
Number of pages: 11
Pages: 91-101
Publication date: 2015
Peer-reviewed: Yes

**Publication information**
Journal: Structural Engineering International
Volume: 25
Issue number: 1
ISSN (Print): 1016-8664
Ratings:
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 0.47 SJR 0.339 SNIP 0.588
Web of Science (2015): Impact factor 0.299
Web of Science (2015): Indexed yes
Original language: English
DOIs:
10.2749/101686614x14043795570011
Source: FindIt
Source-ID: 2263699074
Research output: Contribution to journal › Journal article – Annual report year: 2015 › Research › peer-review
Spherical tuned liquid damper for vibration control in wind turbines

A tuned liquid damper (TLD), which consisted of two-layer hemispherical containers, partially filled with water, was investigated as a cost-effective method to reduce the wind-induced vibration of wind turbines. A 1/20 scaled test model was designed to investigate its performance on the shaking table. Three groups of equivalent ground accelerations were inputted to simulate the wind-induced dynamic response under different load cases. The influence of rotors and nacelle was assumed to be a concentrated tip mass. A series of free and forced vibration experiments were performed on the shaking table. The experimental results indicated that the spherical TLD could effectively improve the damping capacity of the test model. The standard deviation of the dynamic response could be effectively reduced when the excitation frequency was approximately equal to its fundamental frequency. For overspeed and extreme operating gust load cases, the standard deviations of the dynamic responses were reduced more than 40% when the liquid mass was about 2% of the generalized mass; for parking load cases, the corresponding standard deviation was reduced more than 50% when the liquid mass was only 1% of the generalized mass. That is to say, the spherical TLD can effectively improve the anti-fatigue performance of the wind turbine tower.

General information
Publication status: Published
Organisations: Department of Civil Engineering, Section for Structural Engineering, Tongji University
Contributors: Chen, J., Georgakis, C. T.
Number of pages: 11
Pages: 1875-1885
Publication date: 2015
Peer-reviewed: Yes

Publication information
Journal: Journal of Vibration and Control
Volume: 21
Issue number: 10
ISSN (Print): 1077-5463

Ratings:
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 1.12 SJR 0.667 SNIP 0.963
Web of Science (2015): Impact factor 1.643
Web of Science (2015): Indexed yes
Original language: English
Keywords: Shaking table test, tuned liquid damper (TLD), vibration control, wind-induced response, wind turbine, Articles
DOIs: 10.1177/1077546313495911
Source: FindIt
Source-ID: 262814624
Research output: Contribution to journal › Journal article – Annual report year: 2015 › Research › peer-review

A construction and a tension element comprising a cable and a plurality of strakes

The invention provides a construction comprising a structural element and at least one cable (100) arranged in tension to carry at least a part of the weight of the structural element. The cable defines an outer surface (102) onto which a plurality of strakes (104) form protrusions for reducing rain and wind induced vibrations. Each strake has a height being a distance from a strake root part connected to the outer surface of the cable and a strake end part terminating the strake outwards form the cable, a width being transverse to the height, and a length transverse to the height and width and along which length the strake is connected to the cable. The length of each strake is shorter than the circumference of the outer surface, and the height is less than 5 percent of the diameter of the cable.

General information
Publication status: Published
Organisations: Department of Civil Engineering, Section for Structural Engineering
Contributors: Georgakis, C. T., Kleissl, K.
Publication date: 2014

Publication information
IPC: E01D11/00; E01D11/02; E01D11/04; E01D19/16; F15D1/10
Patent number: WO2014001515A1
Filing date: 03/01/2014
Original language: English
A construction and a tension element comprising a cable and one or more strakes

The invention provides a construction comprising a structural element and at least one cable (101) arranged in tension to carry at least a part of the weight of the structural element. The cable defines an outer surface (102) onto which at least one strake (104) forms a protrusion for reducing rain and wind induced vibrations. The strake has a height being a distance from a strake root part connected to the outer surface of the cable and a strake end part terminating the strake outwards away from the cable, and the strake has a width being transverse to the height, the width decreasing in the direction from the strake root part towards the strake end part. The height is less than 5 percent of the diameter of the cable. Furthermore, the strake comprises a first strake surface portion facing away from the cable, which first strake surface portion is concave or straight.

General information
Publication status: Published
Organisations: Department of Civil Engineering, Section for Structural Engineering
Contributors: Georgakis, C. T., Kleissl, K.
Publication date: 2014

A Semi-active Control System for Wind Turbines

A semi-active (SA) control system based on the use of smart magnetorheological (MR) dampers to control the structural response of a wind turbine is proposed herein. The innovative approach is based on the implementation and use of a variable-properties base restraint. This is able to modify in real time its mechanical properties according to the instantaneous decision of a given control logic, the latter addressed to control one or more structural response parameters. The smart base restraint is thought to be a combination of a smooth hinge, elastic springs, large-scale adjustable MR dampers, and a control algorithm that instantaneously commands the latter during the motion, making them to modulate the reactive force as needed to achieve the performance goals. The design and operation of such a system are shown with reference to a case study consisting of an almost 100 m tall wind turbine, realized in a 1/20 scale model at the Denmark Technical University (DTU). Shaking table tests have been performed under the action of two different types of wind loads and by using two purposely written control logics, highlighting the high effectiveness of the proposed SA control technique and encouraging to further investigate in such direction.

General information
Publication status: Published
Organisations: Department of Civil Engineering, Section for Structural Engineering, University of Naples Parthenope
Contributors: Caterino, N., Georgakis, C. T., Trinchillo, F., Occhiuzzi, A.
Pages: 375-407
Publication date: 2014
Evaluation of Damping Using Time Domain OMA Techniques

The prevailing Operational Modal Analysis (OMA) techniques provide in most cases reasonably accurate estimates of structural frequencies and mode shapes. In contrast though, they are known to often produce poor structural damping estimates, which is mainly due to inherent random and/or bias errors. In this paper a comparison is made of the effectiveness of three existing OMA techniques in providing accurate damping estimates for varying loadings, levels of noise, number of added measurement channels and structural damping. The evaluated techniques are derived in the time domain and are namely the Ibrahim Time Domain (ITD), Eigenvalue Realization Algorithm (ERA) and the Polyreference Time Domain (PTD). The response of a two degree-of-freedom (2DOF) system is numerically established from specified modal parameters with well separated and closely spaced modes. Two types of response are considered, free response and random response from white noise loading. Finally, the results of the numerical study are presented, in which the error of the structural damping estimates obtained by each OMA technique is shown for a range of damping levels. From this, it is clear that there are notable differences in accuracy between the different techniques.

General information
Publication status: Published
Organisations: Campus Service, Department of Civil Engineering, Section for Structural Engineering, Aarhus University
Contributors: Bajric, A., Brincker, R., Georgakis, C. T.
Number of pages: 6
Publication date: 2014

Identification of aeroelastic forces and static drag coefficients of a twin cable bridge stay from full-scale ambient vibration measurements

Despite much research in recent years, large amplitude vibrations of inclined cables continue to be of concern for cable-stayed bridges. Various excitation mechanisms have been suggested, including rain-wind excitation, dry inclined cable galloping, high reduced velocity vortex shedding and excitation from the deck and/or towers. Although there have been many observations of large cable vibrations on bridges, there are relatively few cases of direct full-scale cable vibration and wind measurements, and most research has been based on wind tunnel tests and theoretical modelling. This paper presents results from full-scale measurements on the special arrangement of twin cables adopted for the Øresund Bridge. The monitoring system records wind and weather conditions, as well as accelerations of certain cables and a few locations on the deck and tower. Using the Eigenvalue Realization Algorithm (ERA), the damping and stiffness matrices are identified for different vibration modes of the cables, with sufficient accuracy to identify changes in the total effective damping and stiffness matrices due to the aeroelastic forces acting on the cables. The damping matrices identified from the full-scale measurements are compared with the theoretical damping matrices based on the quasi-steady theory, using three different sets of wind tunnel measurements of static force coefficients on similar shaped twin or single cables, with good agreement. The damping terms are found to be dependent on Reynolds number rather than reduced velocity, indicating that Reynolds number governs the aeroelastic effects in these conditions. There is a significant drop in the aerodynamic damping in the critical Reynolds number range, which is believed to be related to the large amplitude cable vibrations observed on some bridges in dry conditions. Finally, static drag coefficients are back-calculated from the full-scale vibration measurements, for first time, with reasonable agreement with direct wind tunnel measurements. The remaining discrepancies are believed to be due to the higher turbulence intensity on site than in the wind tunnel. © 2013 Elsevier Ltd.

General information
Publication status: Published
Organisations: Department of Civil Engineering, Section for Structural Engineering, University of Bristol, University of Leeds
Contributors: Acampora, A., Georgakis, C. T., Macdonald, J., Nikitas, N.
Pages: 90-98
Publication date: 2014
Peer-reviewed: Yes
Measurement of Local Deformations in Steel Monostrands Using Digital Image Correlation

The local deformation mechanisms in steel monostrands have a significant influence on their fatigue life and failure mode. However, the observation and quantification of deformations in monostrands experiencing axial and transverse deformations is challenging because of their complex geometry, difficulties with the placement of strain gauges in the vicinity of the anchorage, and, most importantly, the relatively small magnitude of deformation occurring in the monostrand. This paper focuses on the measurement of localized deformations in high-strength steel monostrands using the digital image correlation (DIC) technique. The presented technique enables the measurement of individual wire strains along the length of the monostrand and also provides quantitative information on the relative movement between individual wires, leading to a more in-depth understanding of the underlying fatigue mechanisms. To validate the proposed image-based measurement method, two different tests were performed, with the one correlation method showing good agreement. Data collected from the DIC technique creates a basis for the analysis of the fretting and localized bending behavior of the monostrand and provides relevant information on the internal state of displacement of the monostrand under bending load.

Recent advances in our understanding of vertical and lateral footbridge vibrations

An extensive amount of research into pedestrian-induced footbridge vibrations has been undertaken over the past 15 years, mainly as a result of the vibrations that plagued the opening of both the Léopold-Sédar-Senghorand and...
Millennium Bridges in Paris and London respectively. Research has focused on evaluating either the vertical or lateral vibrations caused by pedestrians, as it is generally accepted that these two forms of vibration have distinct driving mechanisms. The results of this research have lead to the establishment of several national and international standards and methodologies for the evaluation of footbridge vibrations. Nevertheless, the calculation of the expected vibrations using the various standards and methodologies often provides widely varying results. Furthermore, several important aspects of the vibration mechanisms have generally been ignored or misunderstood. In this paper, a brief review of the recent advances in our understanding of crowd-induced footbridge vibrations is made, with focus on clarifying important aspects of the vibration mechanisms and bringing to attention the relevance of treating human induced loading in a nondeterministic manner.

**General information**
Publication status: Published
Organisations: Department of Civil Engineering, Section for Structural Engineering, Krabbenhøft Consulting Engineers
Contributors: Georgakis, C. T., Ingólfsson, E. T.
Number of pages: 11
Publication date: 2014

**Host publication information**
Title of host publication: Proceedings of Footbridge 2014
Keywords: Pedestrian-induced vertical and lateral vibrations, Crowds, Synchronisation, Random loading

**Bibliographical note**
Keynote lecture
Source: PublicationPreSubmission
Source-ID: 101681281
Research output: Chapter in Book/Report/Conference proceeding – Article in proceedings – Annual report year: 2014

---

**Structural monitoring and smart control of a wind turbine**

The remarkable growth in height of wind turbines in the last years - for a higher production of electricity - makes the issues of monitoring and control of such challenging engineering works pressing than ever. The research herein proposed is addressed to monitor the structural demand imposed to the tower as well as to bound it within given limits thanks to the presence and automatic remote control of smart devices at the base of the tower. The latter are magnetorheological (MR) dampers, i.e. special dissipative devices able to change, almost in real time, their mechanical behaviour according to the intensity of current feeding them. A specific control algorithm is proposed to drive MR dampers during severe wind loads. It aims to instantaneously calibrate the current to be supplied to the MR dampers, i.e. their "stiffness", so as to reduce stresses and displacements imposed to the wind tower. The idea of a variable base restraint for the tower, made up of an hinge and a set of vertical MR dampers, as well as the effectiveness of the above controller, have been experimentally test by means of a shaking table facility at the Denmark Technical University. Two extreme wind loads have been reproduced to assess the control system under very different types of action. The results gathered, encouraging for further investigations, are presented and discussed, also looking at possible further developments.

**General information**
Publication status: Published
Organisations: Department of Civil Engineering, Section for Structural Engineering, University of Naples Parthenope
Contributors: Caterino, N., Trinchillo, F., Georgakis, C. T., Occhiuzzi, A.
Number of pages: 6
Pages: 1-6
Publication date: 2014

**Host publication information**
Title of host publication: Proceedings from IEEE Workshop on Environmental, Energy, and Structural Monitoring Systems (EESMS)
Publisher: IEEE
ISBN (Electronic): 9781479949885
DOIs: 10.1109/EESMS.2014.6923281
Source-ID: 272318319
Research output: Chapter in Book/Report/Conference proceeding – Article in proceedings – Annual report year: 2014
Aerodynamic coefficients of plain and helically filleted twin circular cylinders for varying wind angles of attack

Moderate vibrations continue to be recorded on the Øresund Bridge twin-stay cables. System identification techniques have been applied to investigate the aerodynamic characteristics of the cables based on ambient vibration measurements. As might be expected, the measured aerodynamic damping ratios vary from those estimated through use of aerodynamic coefficients of single circular cylinders, as reported in literature. To address this issue, wind tunnel tests were performed on a 1:2.3 scale section model of the Øresund Bridge cables, with and without the presence of helical fillets. In this paper, the results of those tests are presented for varying wind angles of attack.

General information
Publication status: Published
Organisations: Department of Civil Engineering, Section for Structural Engineering
Contributors: Acampora, A., Georgakis, C. T.
Number of pages: 8
Publication date: 2013

Host publication information
Title of host publication: Proceedings - European and African Conference on wind Engineering
Publisher: International Association for Wind Engineering (IAWE)
Electronic versions:
Aerodynamic_coefficients.pdf
URLs:
http://www.iawe.org/about/6th_eacwe_proceedings.html
Source: dtu
Source-ID: u::8192
Research output: Chapter in Book/Report/Conference proceeding - Article in proceedings – Annual report year: 2013 - Research - peer-review

Change in mass and damping on vertically vibrating footbridges due to pedestrians

Pedestrian-induced footbridge vibrations are an issue that bridge designers often have to contend with. A plethora of research in recent years has led to the development of load models and procedures that allow for the determination of footbridge response. Nonetheless, measured footbridge responses often deviate from those predicted. One of the main deficiencies of the existing models and guidelines is the exclusion of the effect of changes in the footbridge's dynamic properties due to the presence of pedestrians. More specifically, any change in mass and/or damping that a pedestrian might introduce to a bridge will affect the bridge's overall dynamic response. This effect is an element of what is often referred to as human-structure interaction. In this paper, the results of an experimental study to determine the change in mass and damping of a vertically vibrating footbridge due to traversing pedestrians are presented. © The Society for Experimental Mechanics, Inc. 2013.

General information
Publication status: Published
Organisations: Department of Civil Engineering, Section for Structural Engineering
Contributors: Georgakis, C. T., Jørgensen, N. G.
Number of pages: 6
Publication date: 2013

Host publication information
Title of host publication: Proceedings of the SEM IMAC XXXI Conference
Electronic versions:
397_geo.pdf
Source: dtu
Source-ID: u::6991
Research output: Chapter in Book/Report/Conference proceeding - Article in proceedings – Annual report year: 2013 - Research - peer-review

Change in mass and damping on vertically vibrating footbridges due to pedestrians

Pedestrian-induced footbridge vibrations are an issue that bridge designers often have to contend with. A plethora of research in recent years has led to the development of load models and procedures that allow for the determination of footbridge response. Nonetheless, measured footbridge responses often deviate from those predicted. One of the main deficiencies of the existing models and guidelines is the exclusion of the effect of changes in the footbridge's dynamic properties due to the presence of pedestrians. More specifically, any change in mass and/or damping that a pedestrian might introduce to a bridge will affect the bridge's overall dynamic response. This effect is an element of what is often referred to as human-structure interaction. In this paper, the results of an experimental study to determine the change in mass and damping of a vertically vibrating footbridge due to traversing pedestrians are presented. © The Society for Experimental Mechanics, Inc. 2013.
Determination of aerodynamic damping and force coefficients of filleted twin cables in dry conditions through passive-dynamic wind tunnel tests

Moderate amplitude vibrations continue to be reported on the Øresund Bridge cables, although fitted with fillets and dampers. To further investigate the aerodynamics of the bridge’s twin-cable arrangement, 1:2.3 scale passive-dynamic wind tunnel tests of the cables were performed at the DTU/FORCE Technology Climatic Wind Tunnel facility. The measured aerodynamic damping of the twin-cable arrangement in dry conditions was compared to the values obtained from full-scale monitoring and from an analytical model using static force coefficients. The comparison revealed broad agreement in the investigated Re range, as did the force coefficients obtained from dynamic and static tests.

Determination of aerodynamic damping of twin cables in wet conditions through passive-dynamic wind tunnel tests

Moderate amplitude cable vibrations continue to be reported on the cable-stayed Øresund Bridge, despite the presence of helical fillets and dampers. The vibrations are particularly notable in wet conditions, which would suggest a form of rain-induced vibrations (RWIV). A statistical operational modal analysis of the monitored vibrations revealed, in certain conditions and for specific wind velocities, the presence of negative aerodynamic damping. To investigate the observed aerodynamic damping of the twin cable arrangement further, a series of 1:2.3 scale passive-dynamic wind tunnel tests was performed at the DTU/FORCE Technology Climatic Wind Tunnel facility in Kgs. Lyngby, Denmark. Tests were performed for both dry and wet conditions, with and without helical fillets. The specific relative cable-wind angle tested was identified as critical from the aforementioned full-scale monitoring of the bridge cables. For the wet tests, the twin cable surfaces were treated in order to obtain uniform upper and lower water rivulets. The interaction between water rivulets, surface properties and the flow was found to govern the activation of the RWIV mechanism. The resulting aerodynamic damping from wet passive-dynamic wind tunnel tests showed the effect of the helical fillets in preventing the occurrence of negative aerodynamic damping, contrary to the plain cables. © 2013 Taylor & Francis Group, London, UK.
Effects of surface roughness and cross-sectional distortions on the wind-induced response of bridge cables in dry conditions

Theoretical and experimental investigations to date assumed that bridge stay cables can be modelled as ideal circular cylinders and that their aerodynamic coefficients are invariant with wind angle-of-attack. These changes are neglected when the potential for bridge cable instability is evaluated, i.e. in terms of negative aerodynamic damping. On the other hand it has been demonstrated that bridge cables are characterised by local alterations of their inherent surface roughness and shape. Small deviations from ideal circularity determine significant changes with Reynolds number in the static drag and lift coefficients. The present study focuses on the dynamic response of a full-scale yawed bridge cable section model, for varying Reynolds numbers and wind angles-of-attack. Tests results show that the in-plane aerodynamic damping of the bridge cable section, and the overall dynamic response, is strongly affected by changes in the wind angle-of-attack.

Experimental evaluation of the fretting fatigue behavior of high-strength steel monostrands

In this paper, the fretting fatigue behavior of pretensioned high-strength steel monostrands is investigated. A method based on the digital image correlation (DIC) technique was used to quantify the relative movement between individual wires along the length of the monostrand. The experimental data indicate that the interwire movement due to transverse deformations is highest at the neutral axis of the monostrand. The results show that the midspan and the anchorage of the monostrand are the two locations where the combination of tensile strains and the interwire friction is the most unfavorable. Moreover, the paper provides relevant information about the monostrand bending stiffness and the extent of relative displacement between core and outer wires of the monostrand undergoing flexural deformations. The results presented herein are of special interest for the fatigue analysis of modern stay cable assemblies where fretting constitutes the main mechanism of the fatigue life reduction. © 2013 Taylor & Francis Group, London, UK.
Experimental study of the effect of icing on the aerodynamics of circular cylinders - Part II: Inclined flow
In this paper effects of ice accretion on the aerodynamics of plain inclined circular cylinders are examined. Aerodynamic force coefficients are found as a function of Reynolds number for ice produced with varying temperature and yaw angle of the cylinder with respect to the flow. The cylinders are produced from HDPE, as used for bridge stays. Variations in the accretion parameters were chosen to generate the most common natural ice formations, which might also be expected to produce bridge cable vibrations. A parallel paper deals with the case of circular cylinders in cross flow.

General information
Publication status: Published
Organisations: Department of Civil Engineering, Section for Structural Engineering, University of Naples Federico II, Mediterranea University of Reggio Calabria
Contributors: Demartino, C., Georgakis, C. T., Ricciardelli, F.
Number of pages: 8
Publication date: 2013
Peer-reviewed: Yes

Bibliographical note
Orally Presented
Source: dtu
Source-ID: u::8193
Research output: Contribution to conference › Paper – Annual report year: 2013 › Research › peer-review

Preliminary probabilistic prediction of ice/snow accretion on stay cables based on meteorological variables
The scope of the present paper is to present a framework for assessment of the probability of occurrence of ice/snow accretion on bridge cables. The framework utilizes Bayesian Probabilistic Networks and the methodology is illustrated with an example of the cable-stayed Øresund Bridge. The case study focuses on the ice/snow accretion due to the in-cloud icing or precipitation icing mechanisms and includes probabilistic assessments of the meteorological variables influencing the ice/snow accretion on the stay cables. Different probability distribution functions are utilized for the representation of the meteorological variables and evaluated both by goodness-of-fit test and qualitatively. Conditional probability curves are developed to predict the amount of ice accretion given a set of meteorological conditions using the Gaussian Kernel Smoothing method. The fitted probability distribution functions for the meteorological variables and the conditional ice accretion curves are implemented in a Bayesian Probabilistic Network and the annual average number of ice/snow accretion occurrences is estimated.

General information
Publication status: Published
Organisations: Department of Civil Engineering, Section for Structural Engineering, Stanford University
Contributors: Roldsgaard, J. H., Kiremidjian, A., Georgakis, C. T., Faber, M. H.
Publication date: 2013
Peer-reviewed: Yes
Electronic versions:
Preliminary probabilistic prediction of ice_snow accretion on stay cables based on meteorological variables.pdf
Source: dtu
Source-ID: u::7972
Research output: Contribution to conference › Paper – Annual report year: 2013 › Research › peer-review

Tuned rolling-ball dampers for vibration control in wind turbines
With wind turbines growing in size and cost, it is necessary to reduce their dynamic responses and improve their fatigue lifetime. A passive tuned-mass damper (TMD) is a very efficient solution for vibration control in structures subjected to wind excitations. In this study, a tuned rolling-ball damper characterized by single or multiple steel balls rolling in a spherical container is proposed to be mounted on the top of wind turbines to reduce the wind-induced vibration. A 1/20 scale shaking table model was developed to evaluate the control effectiveness of the damper. The wind-induced dynamic responses of the test model with and without TMD were obtained from the shaking table tests. The test results indicated that the rolling-ball dampers could effectively suppress the wind-induced vibration of wind turbines. The damper with three
balls in one container had better control effectiveness than that with only one ball because of the impact effect and the rolling friction. The control effectiveness of the damper cannot be improved further when the number of balls is increased beyond a certain point.

General information
Publication status: Published
Organisations: Department of Civil Engineering, Section for Structural Engineering
Contributors: Chen, J., Georgakis, C. T.
Pages: 5271-5282
Publication date: 2013
Peer-reviewed: Yes

Publication information
Journal: Journal of Sound and Vibration
Volume: 332
Issue number: 21
ISSN (Print): 0022-460x
Ratings:
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 2.61 SJR 1.457 SNIP 2.617
Web of Science (2013): Impact factor 1.857
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
Original language: English
DOIs: 10.1016/j.jsv.2013.05.019
Source: dtu
Source-ID: n::oai:DTIC-ART:elsevier/389391912::30941
Research output: Contribution to journal › Journal article – Annual report year: 2013 › Research › peer-review

Understanding and controlling wind-induced vibrations of bridge cables: Results from the Femern Crossing research project
Following the successful completion of the Storebælt and Øresund Crossings, the Danish Ministry of Transport appointed Femern A/S to be in charge of preparation, investigations and planning in relation to the establishment of a fixed link across the Fehmarnbelt. To further investigate the causes behind the cable vibrations that were observed on the cable-supported bridges forming part of the aforementioned crossings, Femern A/S commissioned a 5-year international collaborative research project, entitled “Understanding and controlling wind-induced vibrations of bridge cables”. The ultimate goal of the project has been the establishment of novel vibration mitigation schemes that could be readily, economically, and effectively implemented on a cable-supported bridge that might form part of the fixed link. In support of the proposed research, Femern A/S commissioned a new climatic wind tunnel, designed specifically for the testing of bridge cables. Five years after its initiation, the participants report the main results from the research project.

General information
Publication status: Published
Organisations: Department of Civil Engineering, Section for Structural Engineering, University of Stavanger, FORCE Technology, University of Bristol, Mediterranea University of Reggio Calabria, Femern A/S
Number of pages: 4
Publication date: 2013
Peer-reviewed: Yes

Bibliographical note
Orally Presented Peer Reviewed Conference Paper
Source: dtu
Source-ID: u::8171
Research output: Contribution to conference › Paper – Annual report year: 2013 › Research › peer-review

Aerodynamic force coefficients of plain bridge cables in wet conditions
In this paper, the aerodynamic forces and force coefficients from preliminary static wind tunnel tests on a plain cable in wet conditions are presented. The presented results are for several different relative cable wind-angles. A comparison is made with tests in dry conditions. In dry conditions, tests were performed for wind velocities between 2 and 31 m/s, whilst in wet conditions tests were performed for the range of wind velocities where rain rivulet formation was found possible, i.e.
between 8-18 m/s. For all of the tested relative cable-wind angles in wet conditions, a reduction in the drag coefficient with increasing Reynolds number, accompanied by a near-zero lift coefficient, was observed. A theoretical evaluation of the aerodynamic damping assuming quasi-steady conditions reveals that changes in drag and lift coefficient are nonetheless not sufficient to generate negative aerodynamic damping. Analysis of the fluctuating lift component shows the presence of “enhanced” vortex shedding at specific wind velocities – similar to what might be observed in the presence of a tripping wire.

General information
Publication status: Published
Organisations: Department of Civil Engineering, Section for Structural Engineering
Contributors: Matteoni, G., Georgakis, C. T.
Number of pages: 10
Publication date: 2012
Peer-reviewed: Yes
Keywords: Inclined bridge cable, Yawed flow, Drag, Lift, Rain, Enhanced vortex shedding
Electronic versions:
prod11347288857179.Matteoni_Georgakis2012_BBAAVII.pdf
Source: dtu
Source-ID: u::4876
Research output: Contribution to conference › Paper – Annual report year: 2012 › Research › peer-review

An evaluation of iced bridge hanger vibrations through wind tunnel testing and quasi-steady theory
Bridge hanger vibrations have been reported under icy conditions. In this paper, the results from a series of static and dynamic wind tunnel tests on a circular cylinder representing a bridge hanger with simulated thin ice accretions are presented. The experiments focus on ice accretions produced for wind perpendicular to the cylinder at velocities below 30 m/s and for temperatures between -5°C and -1°C. Aerodynamic drag, lift and moment coefficients are obtained from the static tests, whilst mean and fluctuating responses are obtained from the dynamic tests. The influence of varying surface roughness is also examined. The static force coefficients are used to predict parameter regions where aerodynamic instability of the iced bridge hanger might be expected to occur, through use of an adapted theoretical 3-DOF quasi-steady galloping instability model, which accounts for sectional axial rotation. A comparison between the 3-DOF model and the instabilities found through two degree-of-freedom (2-DOF) dynamic tests is presented. It is shown that, although there is good agreement between the instabilities found through use of the quasi-steady theory and the dynamic tests, discrepancies exist-indicating the possible inability of quasi-steady theory to fully predict these vibrational instabilities.

General information
Publication status: Published
Organisations: Department of Civil Engineering, Section for Structural Engineering, COWI AS
Contributors: Gjelstrup, H., Georgakis, C. T., Larsen, A.
Number of pages: 23
Pages: 385-407
Publication date: 2012
Peer-reviewed: Yes

Publication information
Journal: Wind & Structures
Volume: 15
Issue number: 5
ISSN (Print): 1226-6116
Ratings:
BFI (2012): BFI-level 1
Scopus rating (2012): CiteScore 1.12 SJR 0.793 SNIP 1.46
Web of Science (2012): Impact factor 1.254
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
Original language: English
Keywords: Circular cylinder, Bridge hangers, Ice accretion, Wind tunnel tests, Aerodynamic instability, Low temperatures, Quasi-steady aerodynamics
Electronic versions:
was1505003.pdf
Source: dtu
Source-ID: u::4834
Research output: Contribution to journal › Journal article – Annual report year: 2012 › Research › peer-review
A preliminary probabilistic framework of the assessment of bridge cable fatigue

In this paper, a basic and preliminary framework for the assessment of cumulative bridge cable fatigue damage due to wind-induced vibrations is presented. The damage assessment is performed using a probabilistic approach, based on a Bayesian Probabilistic Network, where the wind environment, traffic loading, bridge specific parameters and the mechanisms that induce significant cable vibrations are the main input parameters. The suggested framework is illustrated on a case study considering the second longest hanger cable of the Great Belt Bridge outlining how information with respect to meteorological and site-specific conditions can be utilized to assess the probability of occurrence of ice-induced vibrations. The fatigue stress in the cable bending mode is evaluated together with the corresponding fatigue lifetime. The modeling scheme shows flexibility in the sense that the individual variables can be assigned probability structures in consistency with the available data as well as subjective knowledge. Moreover the Bayesian framework directly facilitates updating based on observations and measurements. Future efforts will be directed on inclusion of rain-wind induced vibrations and the combination of fatigue inducing bending and axial stresses.

Comparison of several innovative bridge cable surface modifications

Over the last two decades, several bridge cable manufacturers have introduced surface modifications on the high-density polyethylene (HDPE) sheathing that is installed for the protection of inner cable strands or wires. The modifications are based on research undertaken predominantly in Europe and Japan, with two different prevailing systems: HDPE tubing fitted with helical fillets and tubing with pattern-indented surfaces. In the US and Europe, helical fillets dominate, whilst pattern indented sur-faces are more common in Asia, particularly for long-span cable-stayed bridges. Research into the effectiveness of helical fillets and pattern-indented surfaces has shown that, be-sides their purported ability to suppress rain-wind induced vibrations, they also modestly reduce drag forces at design wind velocities. This is of particular interest to bridge designers, as wind on stay planes of long-span bridges can now produce more than 50% of the overall horizontal load on the bridge (Gimsing and Georgakis, 2012). Recently, the authors presented a comprehensive comparative study of the aerodynamic performance of these existing cable surface modifications (Kleissl and Georgakis, 2011, 2012). The comparison helped to eliminate uncertainties in previous studies, due to the fact that several researchers, in different facilities, with varying wind-tunnel flow characteristics and performance, have developed each separately. During the study, the authors were able to docu-ment the performance advantages of each of the modifications, but often not to the levels that have been commonly reported.

Therefore, similarly to Yagi et al. (2011), several new surface modifications are proposed here-with, in an attempt to combine and enhance the performance advantages of each of the existing modifi-cations. Each of the proposed modifications was investigated through wind tunnel testing. The resulting mean static force coefficients were obtained from wind tunnel tests, with the cables positioned normal to the wind, and were used as “gateway” criteria for the subsequent investigation of rain rivulet suppression.
Comparison of the aerodynamics of bridge cables with helical fillets and a pattern-indented surface

In this paper, the aerodynamics of bridge cables with helical fillets and a pattern-indented surface are examined. To this end, an extensive wind-tunnel test campaign was undertaken to measure the static force coefficients about the critical Reynolds number region, with varying relative cable-wind angles. The tests confirmed that the pattern-indented tubing exhibits the lowest drag coefficient, reaching its supercritical flow state for Reynolds numbers lower than the other cables tested. For this cable, vortex-shedding was found to be present throughout the supercritical range. The asymmetry of the surface pattern introduce a wind-angle of attack dependency that leads to a prediction of Den Hartog galloping instability. For yawed positions, flow transition was found to be independent of the relative cable-wind angle and therefore only governed by the along-wind flow velocity. The helically filleted cable was found to have a much slower flow transition for near normal flow and relatively large lift force components for the yawed positions. Flow visualizations confirmed the existence of specific flow structures which are often associated with the presence of lower drag or large lift forces. The visualization tests confirmed the presence of an axial flow that was greatly hindered by the presence of the helical fillets.

General information
Publication status: Published
Organisations: Department of Civil Engineering, Section for Structural Engineering, Department of Mechanical Engineering
Contributors: Kleissl, K., Georgakis, C.
Pages: 166-175
Publication date: 2012
Peer-reviewed: Yes

Publication Information
Journal: Journal of Wind Engineering & Industrial Aerodynamics
Volume: 104-106
ISSN (Print): 0167-6105
Ratings:
BFI (2012): BFI-level 1
Scopus rating (2012): CiteScore 1.81 SJR 0.792 SNIP 2.423
Web of Science (2012): Indexed yes
Original language: English
Keywords: Bridge cable vibration, Shape modification, Passive aerodynamic control, Pattern-indented surface, Helical fillets, Yawed flow, Axial flow
DOIs:
10.1016/j.jweia.2012.02.031
Source: dtu
Source-ID: n::oai:DTIC-ART:elsevier/365742769::16939
Research output: Contribution to journal › Journal article – Annual report year: 2012 › Research › peer-review

Effects of bridge cable surface roughness and cross-sectional distortion on aerodynamic force coefficients

Theoretical and experimental investigations to date have assumed that bridge cables can be modeled as ideal circular cylinders and the associated aerodynamic coefficients are invariant with the wind angle-of-attack. On the other hand, bridge cables are normally characterized by local alterations of their inherent surface roughness and shape, which might present a significant disturbance for the surrounding wind flow. The present study focuses on the experimental determination, based on static wind tunnel tests, of the aerodynamic coefficients of full-scale bridge cable section models both perpendicular and inclined to the flow, for varying wind angles-of-attack. The wind tunnel test results demonstrate that the aerodynamic coefficients of bridge cables can be significantly affected by the wind angle-of-attack.

General information
Publication status: Published
Organisations: Department of Civil Engineering, Section for Structural Engineering
Contributors: Matteoni, G., Georgakis, C.
Pages: 176-187
Publication date: 2012
Peer-reviewed: Yes

Publication Information
Journal: Journal of Wind Engineering & Industrial Aerodynamics
Volume: 104-106
ISSN (Print): 0167-6105
Ratings:
BFI (2012): BFI-level 1
Scopus rating (2012): CiteScore 1.81 SJR 0.792 SNIP 2.423
Web of Science (2012): Impact factor 1.342
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
Original language: English
Keywords: Bridge cable, Surface roughness, Shape distortion, Turbulence, Inclined cable
DOIs: 10.1016/j.jweia.2012.02.029
Source: dtu
Source-ID: n::oai:DTIC-ART:elsevier/365742770::16940
Research output: Contribution to journal › Journal article – Annual report year: 2012 › Research › peer-review

Experimental study of ice accretion on circular cylinders at moderate low temperatures

For the assessment of aerodynamic instability of iced bridge cables various calculation models are available. Input for these models are amongst others aerodynamic load coefficients usually determined in wind tunnel tests on generic or simplified models of iced cable sections. Even though icing of structures is widely studied, the particular climatic boundary conditions regarding bridge cable vibrations have so far been omitted. The presented study was performed in March 2009 in the Altitude Icing Wind Tunnel at the National Research Council of Canada (NRC) in Ottawa with the purpose of establishing detailed knowledge on the shape characteristics of ice accretion on circular cylinders under the specific conditions where large amplitude vibration of iced bridge have been observed in nature. Hence, the study shall serve as a reference and the results will be used for validation of numerical and experimental simulations and for future work in a recently developed climatic wind tunnel facility specifically built to investigate cable vibration.

General information
Publication status: Published
Organisations: Department of Civil Engineering, Section for Structural Engineering, COWI AS
Contributors: Koss, H. H., Gjelstrup, H., Georgakis, C. T.
Pages: 540-546
Publication date: 2012
Peer-reviewed: Yes

Publication information
Journal: Journal of Wind Engineering & Industrial Aerodynamics
Volume: 104-106
ISSN (Print): 0167-6105
Ratings:
BFI (2012): BFI-level 1
Scopus rating (2012): CiteScore 1.81 SJR 0.792 SNIP 2.423
Web of Science (2012): Impact factor 1.342
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
Original language: English
Keywords: Wind tunnel testing, Ice accretion, Bridge cables, In-cloud icing, Surface shapes
DOIs: 10.1016/j.jweia.2012.03.024
Source: dtu
Source-ID: n::oai:DTIC-ART:elsevier/365742809::16941
Research output: Contribution to journal › Journal article – Annual report year: 2012 › Research › peer-review

Identification of aeroelastic forces on twin bridge cables from full-scale measurements in skew winds

Despite much research in recent years, large amplitude vibrations of inclined bridge cables continue to be of concern. Various mechanisms for the excitation have been suggested, including rain-wind excitation, dry inclined cable galloping, high reduced-velocity vortex shedding and excitation from the deck and/or towers.

Since 2010, the Technical University of Denmark has been monitoring the vibrations of the twin inclined cables of the Øresund Bridge. From the acquired data, Georgakis and Acampora [1] showed that the cable aerodynamic damping can be determined for wind orthogonal to the twin cables, in dry and wet conditions. In parallel, Acampora et al. [2] showed for the same cables that both coupled and uncoupled aeroelastic forces can be determined from the monitoring data, again when the wind is orthogonal to the cable and in dry conditions. In an expansion of the previous work, the aim of this paper is to identify the aeroelastic forces for in-plane and out-of-plane vibrations of bridge cables in dry conditions as in [2], but now for skewed winds. To achieve this, an output-only system identification employing the Eigenvalue Realisation Algorithm (ERA) [3] has been applied to selected vibration events. From this, the effective stiffness and damping matrices (including aeroelastic effects) have been identified from the cable vibrations.
Localized bending fatigue behavior of high-strength steel monostrands

In this paper, the localized bending fatigue behavior of pretensioned high strength steel monostrands is investigated. Furthermore, a new methodology using an optical photogrammetry system, which can quantify surface deformations on the strand is presented. The system allows measurement of the strain distribution in the strand and helps in identifying potential failure mechanisms along the strand and at the wedge location. Initial analysis of the deformations shows that the bending fatigue behavior of the monostrand may be controlled either by local bending deformations or by relative displacement (opening/closing and sliding) of the helically wound wires. Moreover, the results are a step towards understanding the bending fatigue damage mechanisms of monostrand cables.

Measurement of localized deformations in high-strength steel cables

Pedestrian-induced lateral forces on footbridges

This paper investigates the phenomenon of excessive pedestrian-induced lateral vibrations as observed on several high-profile footbridges. The vibrations are a consequence of human-structure interaction, in which the forces generated by the pedestrians depend strongly on the vibration of the underlying pavement. An extensive experimental analysis has been carried out to determine the lateral forces generated by pedestrians when walking on a laterally moving treadmill. Two different conditions are investigated; initially the treadmill is fixed and then it is laterally driven in a sinusoidal motion at varying combinations of frequencies (0.33-1.07 Hz) and amplitudes (4.5-48 mm). The component of the pedestrian-
induced force which is caused by the laterally moving surface is herewith quantified through equivalent velocity and acceleration proportional coefficients. It is shown that large amplitude lateral vibrations are the results of correlated pedestrian forces in the form of negative damping, with amplitudes that depend on the relationship between the step frequency and the frequency of the lateral movement.

**General information**
Publication status: Published
Organisations: Department of Civil Engineering, Section for Structural Engineering
Contributors: Ingolfsson, E. T., Georgakis, C. T., Jönsson, J., Ricciardelli, F.
Pages: 63-69
Publication date: 2012
Peer-reviewed: Yes

**Publication information**
Journal: Noise & Vibration Bulletin
ISSN (Print): 0144-7785
Ratings:
ISI indexed (2012): ISI indexed no
Original language: English
Source-ID: n::oai:DTIC-ART:inspec/380648729::26652
Research output: Contribution to journal › Journal article – Annual report year: 2012 › Research › peer-review

**Pedestrian-induced lateral vibrations of footbridges: A literature review**
The earliest scientific descriptions of excessive pedestrian-induced lateral vibrations are dated back to the 1970s, but it was not until the beginning of the new millennium that bridge engineers fully comprehended the potential negative effect of pedestrian crowds on long-span footbridges. Following the unexpected serviceability failures of Paris’ Solférino and London’s Millennium footbridges in 1999 and 2000, a new tract of research was initiated, focused on understanding the phenomenon which has become known as Synchronous Lateral Excitation (SLE). In this paper, a comprehensive review of studies related to pedestrian-induced lateral vibrations of footbridges is provided, primarily focusing on studies published within the last decade. Research in this field can generally be split into three categories; (i) fullscale testing of existing bridges subject to crowd loading, (ii) laboratory studies on human-structure interaction between single pedestrians and laterally moving platforms and (iii) mathematical modelling of the pedestrian-induced load. It is shown herein, that a significant amount of research has been carried out within each of the three categories, but there is only limited interconnection, particularly between the mathematical models on one side and the empirical observations on the other. The main purpose of this review is to provide this link, through a detailed and critical review of publications within each of the three categories.

**General information**
Publication status: Published
Organisations: Department of Civil Engineering, Section for Structural Engineering
Contributors: Ingólfsson, E. T., Georgakis, C. T., Jónsson, J.
Pages: 21-52
Publication date: 2012
Peer-reviewed: Yes

**Publication information**
Journal: Engineering Structures
Volume: 45
ISSN (Print): 0141-0296
Ratings:
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 2.23 SJR 1.95 SNIP 2.656
Web of Science (2012): Impact factor 1.713
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
Original language: English
Keywords: Footbridges, Lateral vibration, Human-structure interaction, Full-scale testing, Load models, Experimental investigations, Ground reaction forces
DOIs:
10.1016/j.engstruct.2012.05.038
Research output: Contribution to journal › Journal article – Annual report year: 2012 › Research › peer-review
Wind-induced Vibrations in the European Court Towers
Issues regarding occupancy comfort in vibration-sensitive structures are the motivation of this study concerning wind-induced vibrations in the European Court Towers in Luxembourg. In one of the two identical towers tuned liquid dampers (TLD) have been installed. Recent studies investigate the changes in the dynamic behavior of the artificially damped tower, before and after the activation of TLD's. This paper widens these investigations and exploits the benefit of having two similar full-scale structures with dissimilar damping characteristics. The main subject of interest in the investigation is the difference in vibration level as well as the modal damping ratios of the towers at various excitation levels. The experimental measurements that form the basis of this paper were conducted during a period of two weeks in the fall of 2010. The modal parameters are extracted using operational modal analysis at different wind speeds and directions. This paper presents the experimental setup and the results of the analysis regarding the differences in response and modal damping ratios of the two towers under varying excitation levels.

General information
Publication status: Published
Organisations: Section for Structural Engineering, Department of Civil Engineering, Aarhus University
Contributors: Hansen, J. B., Brincker, R., Andersen, K. G., Andersen, S., Georgakis, C. T.
Publication date: 2012

Host publication information
Title of host publication: Proceedings of the SEM IMAC XXX Conference
URLs:
http://sem.org/CONF-IMAC-TOP.asp
Source: orbit
Source-ID: 318824
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2012 › Research › peer-review

Aerodynamic coefficients of dry inclined cables in smooth flow
General information
Publication status: Published
Organisations: Department of Civil Engineering, Section for Structural Engineering
Contributors: Matteoni, G., Georgakis, C.
Publication date: 2011

Host publication information
Title of host publication: Proceedings of 9th International Symposium on Cable Dynamics
Source-ID: 286435
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2011 › Research › peer-review

Aerodynamic coefficients of stationary dry inclined bridge cables in laminar flow
Stay cables are the most flexible elements of cable-stayed bridges. When exposed to wind loading, they often undergo large amplitude vibrations, thus motivating serious design concerns. In most cases, vibrations are observed in the presence of water rivulets or ice accretions, which lead to an effective change in the cable cross section, and its aerodynamic properties. On the other hand, divergent, self-excited vibrations have been observed in the field also for dry, inclined stay cables, in warm temperatures. The need for reliable design guidelines for inclined stay cables has motivated experimental and theoretical research in the last two decades, even though a definitive understanding of the flow around inclined cables under various surface conditions has not been achieved. A comparative study on the aerodynamic coefficients of stationary inclined stay cables, under various surface conditions, i.e. dry, wet and icy, in laminar and turbulent flow, has been initiated at the new DTU/Force Climatic Wind Tunnel facility in Denmark. This paper covers selected results of the comparative study, i.e. aerodynamic coefficients of dry inclined cables in laminar flow conditions.

General information
Publication status: Published
Organisations: Department of Civil Engineering, Section for Structural Engineering, Mediterranea University of Reggio Calabria
Contributors: Matteoni, G., Georgakis, C., Ricciardelli, F.
Publication date: 2011

Host publication information
Title of host publication: Proceedings of the XIII Italian Steel Conference
Aerodynamic control of bridge cables through shape modification: A preliminary study

This paper examines the viability of modifying bridge cable shape and surface for the purpose of controlling wind-induced vibrations. To this end, an extensive wind-tunnel test campaign was carried out on various cable shapes about the critical Reynolds number region. Cable shapes were chosen to passively modify the flow in a particular manner. Tested shapes included those which have some form of waviness, faceting and shrouding. Section models were tested using a static inclined rig, allowing them to be installed at yawed cable–wind angles for both smooth and turbulent flow conditions. The aerodynamic damping of the tested cylinders is evaluated by applying both 1- and 2-dof quasi-steady aerodynamic instability models. This allows for the prediction of regions of aerodynamic instability, as a function of flow angle and Reynolds number. Whilst the plain, wavy and faceted cylinders are predicted to suffer from either dry inclined galloping, “drag crisis” or Den Hartog galloping, the shrouded cylinder is found to be stable for all angles of attack, albeit with an increase in drag at typical design wind velocities. Finally, turbulent flow is found to introduce an increased amount of aerodynamic damping mainly by providing a more constant lift force over tested Reynolds numbers.

General information
Publication status: Published
Organisations: Section for Structural Engineering, Department of Civil Engineering
Contributors: Kleissl, K., Georgakis, C.
Pages: 1006-1020
Publication date: 2011
Peer-reviewed: Yes

Publication information
Journal: Journal of Fluids and Structures
Volume: 27
ISSN (Print): 0889-9746
Ratings:
BFI (2011): BFI-level 1
Scopus rating (2011): CiteScore 2.16 SJR 1.499 SNIP 2.534
Web of Science (2011): Impact factor 1.567
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
Original language: English
Keywords: Bridge cable vibration, Shape modification, Yawed flow, Passive aerodynamic damping, Aerodynamic stability
DOIs:
10.1016/j.jfluidstructs.2011.04.012
Source: orbit
Source-ID: 286374
Research output: Article in proceedings – Annual report year: 2011

A preliminary bending fatigue spectrum for steel monostrand cables

This paper presents the results of the experimental study on the bending fatigue resistance of high-strength steel monostrand cables. From the conducted fatigue tests in the high-stress, low-cycle region, a preliminary bending fatigue spectrum is derived for the estimation of monostrand cable service life expectancy. The presented preliminary bending fatigue spectrum of high-strength monostands is currently unavailable in the published literature. The presented results provide relevant information on the bending mechanism and fatigue characteristics of monostrand steel cables in tension and flexure and show that localized cable bending has a pronounced influence on the fatigue resistance of cables under dynamic excitations.

General information
Publication status: Published
Organisations: Section for Structural Engineering, Department of Civil Engineering, COWI AS
Contributors: Winkler, J., Fischer, G., Georgakis, C. T., Kotas, A.
Pages: 249-255
Publication date: 2011
Peer-reviewed: Yes
A Preliminary Bending Fatigue Spectrum for Steel Monostrand Cables

General information
Publication status: Published
Organisations: Section for Structural Engineering, Department of Civil Engineering
Contributors: Winkler, J., Fischer, G., Georgakis, C. T., Kotas, A.
Publication date: 2011

Host publication information
Title of host publication: Proceedings
Keywords: Bending fatigue spectrum, High-strength monostrand steel cable, Cyclic loading
Electronic versions:
A Preliminary Bending Fatigue.pdf
Source: orbit
Source-ID: 316359

A quasi-steady 3 degree-of-freedom model for the determination of the onset of bluff body galloping instability
In this paper, a quasi-steady three degree-of-freedom (3-dof) flow-induced galloping instability model for bluff-bodies is proposed. The proposed model can be applied generally for the prediction of onset of galloping instability due to negative aerodynamic damping of any prismatic compact bluff body in a fluidic medium. The three degrees of freedom refer to the bluff body’s two orthogonal displacements perpendicular to its length axis and the rotation about its length axis. The model incorporates inertial coupling between the three degrees of freedom and is capable of estimating the onset of galloping instability due changes in drag, lift and moment, assuming that the bluff body is subject to uniform flow and motion. The changes may be a function of wind angle of attack (a) perpendicular to bluff body’s length axis, Reynolds number and a skew wind angle (f) in relation to the length axis of the bluff body. An analytical solution of the instability criterion is obtained by applying the Routh–Hurwitz criterion.

General information
Publication status: Published
Organisations: Section for Structural Engineering, Department of Civil Engineering, COWI AS
Contributors: Gjelstrup, H., Georgakis, C.
Pages: 1027-1034
Publication date: 2011
Peer-reviewed: Yes

Publication information
Journal: Journal of Fluids and Structures
Volume: 27
Issue number: 7
ISSN (Print): 0889-9746
Ratings:
BFI (2011): BFI-level 1
Scopus rating (2011): CiteScore 2.16 SJR 1.499 SNIP 2.534
Web of Science (2011): Impact factor 1.567
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
Original language: English
Keywords: Routh–Hurwitz, Quasi-steady drag, Negative aerodynamic damping, Bluff body, Motional instability, Lift and moment
A stochastic load model for pedestrian-induced lateral forces on footbridges
In the past decade, several researchers have studied the phenomenon of excessive pedestrian-induced lateral vibrations and full-scale measurements of various bridges under crowd loading have been carried out. These tests have verified the existence of a form of instability for which a transition between limited and excessive lateral vibrations occurs for a small increase in the number of people occupying the bridge. This disproportionate increase in the lateral vibration amplitude is caused by a dynamic interaction between the pedestrian and the laterally moving structure, although the governing mechanism which generates the load is still somewhat disputed. Theoretical work has also been undertaken, but unlike current codes of practice and design guidelines, which are primarily based on the empirical full-scale observations, many of the theoretical hypotheses lack the proper experimental evidence to support their applicability. Recently, an extensive experimental campaign was carried out, in which the lateral forces generated by pedestrians during walking on a laterally moving treadmill were determined for various combinations of lateral frequencies (0.33–1.07 Hz) and amplitudes (4.5–48 mm). It was shown that large amplitude vibrations are the result of correlated pedestrian forces in the form of “negative damping”, with magnitudes that depend on the relationship between the pacing frequency and the frequency of the lateral movement. Hereewith, a novel stochastic load model for the frequency and amplitude dependent pedestrian-induced lateral forces is presented. The lateral forces are modelled as a sum of an “equivalent static force” and “motion-induced” (or self-excited) forces which are quantified through equivalent pedestrian damping and mass coefficients. The parameters in the model are based directly on measured lateral forces from a large group of pedestrians. Thereby, the model is currently the most statistically reliable analytical tool for modelling of pedestrian-induced lateral vibrations. Through simplified numerical simulations, it is shown that the modal response of a footbridge subject to a pedestrian crowd is sensitive to the selection of the pacing rate distribution within the group, the magnitude of ambient wind loads and the total duration of the load event. In a particular simulation, the selection of these parameters ultimately affects the critical number of pedestrians needed to trigger excessive vibrations. Finally, as an example, it is shown that the prediction of the critical number of pedestrians matches well with observations made during the opening of the London Millennium Bridge.

General information
Publication status: Published
Organisations: Section for Structural Engineering, Department of Civil Engineering
Contributors: Ingólfsson, E. T., Georgakis, C.
Pages: 3454-3470
Publication date: 2011
Peer-reviewed: Yes

Publication information
Journal: Engineering Structures
Volume: 33
Issue number: 12
ISSN (Print): 0141-0296
Ratings:
BFI (2011): BFI-level 2
Scopus rating (2011): CiteScore 2.26 SJR 1.773 SNIP 2.726
Web of Science (2011): Impact factor 1.351
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
Original language: English
Keywords: Lateral vibration, Pedestrian, Footbridges, Stochastic, Load model
DOIs:
10.1016/j.engstruct.2011.07.009
Source: orbit
Source-ID: 286192
Research output: Contribution to journal › Journal article – Annual report year: 2011 › Research › peer-review

Cable Supported Bridges: Concept and Design

General information
Publication status: Published
Organisations: Section for Structural Engineering, Department of Civil Engineering
Contributors: Gimsing, N. J., Georgakis, C.
Comparison of the aerodynamics of bridge cables with helical fillets and a pattern-indented surface in normal flow
Over the last two decades, several bridge cable manufacturers have introduced surface modifications on the high-density polyethylene (HDPE) sheathing that is often installed for the protection of inner strands. The main goal of this is rain rivulet impedance, leading to the suppression of rain-wind induced vibrations (RWIVs). The modifications are based on research undertaken predominantly in Europe and Japan, with two different systems prevailing; HDPE tubing fitted with helical surface fillets and HDPE tubing with pattern-indented surfaces. In the US and Europe, helical fillets dominate, whilst pattern indented surfaces are more common in Asia. Research into the effectiveness of helical fillets and pattern-indented surfaces has shown that, besides their potential to suppress rain-wind induced vibrations, they are also modestly reducing drag forces at design wind velocities. This is of particular interest to bridge design-ers, as wind on stay planes of long bridges can now produce more than 50% of the overall horizontal load on a bridge. Nevertheless, there is no definitive aerodynamic performance comparison between the two systems. One of the problems of comparing them lies in the fact that different researchers, in different facilities, with varying wind-tunnel flow characteristics and performance, have developed each separately. As part of a comprehensive review of the aerodynamics of existing cable surface modifications, the resulting static force coefficients obtained from wind-tunnel tests on cables normal to flow and employing both systems are presented herewith and compared to those from a plain reference cylinder. This is the first known direct comparison of this type. Evaluation of lift force fluctuations and flow visualisation tests are also undertaken to obtain insight into the structures of the flow around the modified profiles.

General information
Publication status: Published
Organisations: Section for Structural Engineering, Department of Civil Engineering
Contributors: Kleissl, K., Georgakis, C.
Publication date: 2011

Host publication information
Title of host publication: International Conference on Wind Engineering
Volume: CD-ROM
URLs:
http://www.icwe13.org/
Source: orbit
Source-ID: 278968
Research output: Chapter in Book/Report/Conference proceeding > Article in proceedings – Annual report year: 2011 > Research > peer-review

Comparison of the aerodynamics of yawed bridge cables with helical fillets and a pattern-indented surface

General information
Publication status: Published
Organisations: Section for Structural Engineering, Department of Civil Engineering
Contributors: Kleissl, K., Georgakis, C.
Publication date: 2011

Host publication information
Title of host publication: Proceedings of 9th International Symposium on Cable Dynamics
Source: orbit
Source-ID: 286389
Research output: Chapter in Book/Report/Conference proceeding > Article in proceedings – Annual report year: 2011 > Research > peer-review

Determination of the aerodynamic damping of dry and wet bridge cables from full-scale monitoring
**Effects of bridge cable surface roughness and cross-sectional distortion on aerodynamic force coefficients**

*General information*
Publication status: Published
Organisations: Department of Civil Engineering, Section for Structural Engineering
Contributors: Matteoni, G., Georgakis, C.
Publication date: 2011

*Host publication information*
Title of host publication: Proceedings of the 13th International Conference Wind Engineering
Source: orbit
Source-ID: 286154

**Estimation of Damping for one of the new European Court Towers in Luxembourg**

The two new high rise buildings for the European court in Luxembourg have been tested by a harmonic shaker and by Operational Modal Analysis. The background for the tests is to estimate the influence on the damping of one of the towers from a series of Tuned Liquid Dampers (TLDs) placed on top of the building. The TLDs have been designed to minimise the response of the buildings to wind loading, resulting in an increase in occupancy comfort. The harmonic excitation is performed to estimate the damping at a displacement level corresponding to significant wind loading whereas the OMA has been performed under minimum wind loading. The paper presents the testing programme and the main results of which one is a clear non-linear behaviour of the introduced viscous damping system.

*General information*
Publication status: Published
Organisations: Section for Structural Engineering, Department of Civil Engineering, Aarhus University, University of Southern Denmark, INCA Ingenieurs Conseils Associés
Contributors: Brincker, R., Brandt, A., Georgakis, C., Roldsgaard, J. H., Schilz, D.
Pages: 373-381
Publication date: 2011

*Host publication information*
Title of host publication: Civil Engineering Topics : Proceedings of the 29th IMAC, A Conference on Structural Dynamics
Volume: 4
Publisher: Springer
Editor: Proulx, T.
ISBN (Print): 9781441993151
Source: orbit
Source-ID: 272361

**Experimental identification of pedestrian-induced lateral forces on footbridges**

This paper presents a comprehensive experimental analysis of lateral forces generated by single pedestrians during continuous walking on a treadmill. Two different conditions are investigated; initially the treadmill is fixed and then it is laterally driven in a sinusoidal motion at varying combinations of frequencies (0.33-1.07 Hz) and amplitudes 4.5-48 mm. The experimental campaign involved seventy-one male and female human adults and covered approximately 55 km of walking distributed between 4954 individual tests. When walking on a laterally moving surface, motion-induced forces develop also at the frequency of the movement and are herewith quantified as equivalent velocity and acceleration proportional coefficients. Their dependency on both the vibration frequency and amplitude is presented, both in terms of mean values and probabilistically to illustrate the randomness associated with both intra and inter-subject variability. It is
shown that the motion induced portion of the pedestrian load (on average) inputs energy into the structure in the frequency range (normalised by the average walking frequency) between approximately 0.6 and 1.2. Furthermore, it is shown that the load component in phase with the acceleration of the treadmill depends on the frequency of the movement, such that pedestrians (on average) add to the overall modal mass for low frequency motion and subtract from the overall modal mass at higher frequencies.

### General information
- **Publication status:** Published
- **Organisations:** Section for Structural Engineering, Department of Civil Engineering, Mediterranea University of Reggio Calabria
- **Contributors:** Ingólfsson, E. T., Georgakis, C., Ricciardelli, F., Jönsson, J.
- **Pages:** 1265-1284
- **Publication date:** 2011
- **Peer-reviewed:** Yes

### Publication information
- **Journal:** Journal of Sound and Vibration
- **Volume:** 330
- **Issue number:** 6
- **ISSN (Print):** 0022-460X
- **Ratings:**
  - BFI (2011): BFI-level 2
  - Scopus rating (2011): CiteScore 2.05 SJR 1.456 SNIP 2.71
  - Web of Science (2011): Impact factor 1.588
  - ISI indexed (2011): ISI indexed yes
- **Original language:** English
- **Keywords:** Lateral vibration, Treadmill, Footbridges, Synchronisation
- **DOIs:** 10.1016/j.jsv.2010.09.034

### Experimental Study of ice accretion on circular cylinders at moderate low temperatures

#### General information
- **Publication status:** Published
- **Organisations:** Section for Structural Engineering, Department of Civil Engineering, COWI AS
- **Contributors:** Koss, H., Gjelstrup, H., Georgakis, C.
- **Publication date:** 2011

#### Host publication information
- **Title of host publication:** International Conference on Wind Engineering
- **Volume:** CD-ROM
- **URLs:** http://www.icwe13.org/

### Fatigue-induced bridge stay cable failures: a review

#### General information
- **Publication status:** Published
- **Organisations:** Section for Structural Engineering, Department of Civil Engineering
- **Contributors:** Winkler, J., Georgakis, C.
- **Publication date:** 2011

#### Host publication information
- **Title of host publication:** Proceedings of 9th International Symposium on Cable Dynamics
- **Source:** orbit
Fatigue testing of monostrands for stay cables under reversed cyclic flexural loading

General information
Publication status: Published
Organisations: Section for Structural Engineering, Department of Civil Engineering, DYWIDAG-Systems International GmbH
Contributors: Brand, W., Märzluf, A., Fischer, G., Georgakis, C.
Publication date: 2011

Host publication information
Title of host publication: fib Symposium Prague 2011
Electronic versions:
PRAGUE_2011_Short_Paper_202_Brand.pdf
URLs:
http://www.fib2011prague.eu/
Source: orbit
Source-ID: 272800

Identification of aeroelastic forces on bridge cables from full-scale measurements
Despite much research in recent years, large amplitude vibrations of inclined cables continue to be of concern for cable-stayed bridges. Various mechanisms have been suggested for their excitation, including rain-wind excitation, dry inclined cable galloping, high reduced velocity vortex shedding and excitation from the deck and/or towers. Although some experiences have been done with full-scale measurements of inclined cables, many of the results available are based on wind tunnel tests and theoretical modelling. This paper presents results from full-scale measurements on the cables of the Øresund Bridge. The system records wind conditions and weather conditions, as well as accelerations of certain cables and a few locations on the deck and tower. Using state-of-the-art methods of output-only system identification, the vibration modes of the cables have been identified. From these modes, the aeroelastic forces acting on the cables are identified and in particular their total effective damping and stiffness matrices. A comparison between damping matrices identified from experimental data of the cables accelerations and theoretical data based on quasi-steady theory and on wind tunnel data from two different cables have been made.

General information
Publication status: Published
Organisations: Section for Structural Engineering, Department of Civil Engineering, University of Bristol
Contributors: Acampora, A., Macdonald, J., Georgakis, C.
Publication date: 2011

Host publication information
Title of host publication: EVACES 2011 – Experimental Vibration Analysis for Civil Engineering Structures
URLs:
http://ing.univaq.it/evaces_2011/
Source: orbit
Source-ID: 286338

Pedestrian-induced lateral forces on footbridges
This paper investigates the phenomenon of excessive pedestrian-induced lateral vibrations as observed on several high-profile footbridges. The vibrations are a consequence of human-structure interaction, in which the forces generated by the pedestrians depend strongly on the vibration of the underlying pavement. An extensive experimental analysis has been carried out to determine the lateral forces generated by pedestrians when walking on a laterally moving treadmill. Two different conditions are investigated; initially the treadmill is fixed and then it is laterally driven in a sinusoidal motion at varying combinations of frequencies (0.33-1.07 Hz) and amplitudes (4.5-48 mm). The component of the pedestrian-induced force which is caused by the laterally moving surface is herewith quantified through equivalent velocity and acceleration proportional coefficients. It is shown that large amplitude lateral vibrations are the results of correlated pedestrian forces in the form of negative damping, with amplitudes that depend on the relationship between the step frequency and the frequency of the lateral movement.
Recent monitoring of the Øresund Bridge: Observations of rain-wind induced cable vibrations

In 1999, 2m amplitude cable vibrations were observed on the Øresund Bridge. The vibrations were attributed to a change in cable shape due to sleet accretion. Subsequent monitoring of the bridge, though, revealed other vibration events due to rain-wind induced mechanisms and parametric excitation (Svensson et al., 2004) – albeit of smaller amplitudes. After two significant cable vibration events, inspections of the cable anchorages revealed failures in the damping systems that had been installed to prevent oscillations. Improvements in the damping systems were introduced and additional tuned mass dampers were installed on the longest and second longest cable pairs. Although the bridge has not suffered from any significant vibration events since the installation of the new damping systems, smaller amplitude vibrations are recorded from time to time. Peak to peak amplitudes of up to three cable diameters have been observed, although the most frequent observations are of smaller amplitude and are almost always in combination with rain. In this paper, several observations are made, regarding the rain-wind induced vibrations (RWIVs) of the cables, based on a relatively brief full-scale monitoring campaign from January 2010 – December 2010. The monitoring shows that there is a direct correlation between wind-cable angles, wind velocities and the amount of rainfall.

The Response Spectrum Methodology considering inter- and intra-subject variability

General information
Publication status: Published
Organisations: Section for Structural Engineering, Department of Civil Engineering, Hunan University
Contributors: Li, H., Georgakis, C., Chen, Z. Q.
Publication date: 2011

Host publication information
Title of host publication: International Conference on Wind Engineering
Volume: CD-ROM
URLs:
http://www.icwe13.org/
Source: orbit
Source-ID: 278970
Bridge Cables - and Wind, Rain, Ice and Snow

General information
Publication status: Published
Organisations: Section for Structural Engineering, Department of Civil Engineering
Contributors: Koss, H., Georgakis, C., Larsen, S. V.
Pages: 52-55
Publication date: 2010
Peer-reviewed: Yes

Publication information
Journal: Wind Tunnel International
Volume: 1
Original language: English
Source: orbit
Source-ID: 270764
Research output: Contribution to journal › Journal article – Annual report year: 2010 › Research › peer-review

Bridge ice accretion and de- and anti-icing systems: A review
Blocks of ice or snow falling from bridge members can cause traffic accidents, direct damages to passing vehicles, and generally place human safety at risk. Consequently, the lack of successful de- or anti-icing measures may result in bridge closure, which leads to traffic hindrance that can in turn lead to severe financial losses. This paper presents a review of the different de- and anti-icing techniques, already developed or in development, which could be applied to bridge cables or pylons. Furthermore, the fundamentals of icing caused by freezing precipitation and in-cloud icing are presented together with the physical mechanisms expected to induce ice shedding.

General information
Publication status: Published
Organisations: Section for Structural Engineering, Department of Civil Engineering
Contributors: Kleissl, K., Georgakis, C.
Number of pages: 227
Pages: 161-167
Publication date: 2010

Host publication information
Title of host publication: The 7th Internation Cable Supported Bridge Operators' Conference : Proceedings
Electronic versions: ICSBOC2010 paper.pdf
Source: orbit
Source-ID: 262680
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2010 › Research › peer-review

Lateral human-structure interaction on footbridges

General information
Publication status: Published
Organisations: Section for Structural Engineering, Department of Civil Engineering, Mediterranea University of Reggio Calabria, University of Florence
Contributors: Ingólfsson, E. T., Georgakis, C., Ricciardelli, F., Procino, L.
Publication date: 2010

Host publication information
Title of host publication: 10th International Conference on Recent Advances in Structural Dynamics
Keywords: Footbridge, human-structure interaction, lateral vibration, synchronisation
Source: orbit
Pedestrian induced vertical vibrations: Response to running using the Response Spectrum Method

Footbridges are increasingly prone to vibrations and designers are generally unable to predict pedestrian-induced vertical vibrations. Many aspects of human loading are not accurately taken into account in the load models employed by the international codes of practice, such as the randomness of crowds travelling across the footbridge. Moreover, these codes, for most of the part, do not deal with pedestrian loading other than walking, even though running and jumping can often produce larger loads and vibration amplitudes. In this paper, an investigation into the response of footbridges under human-induced loading due to running is undertaken. To this end, Monte Carlo simulations are adopted for the generation of crowd loading. A reference response spectrum, defined as the peak acceleration associated with a given return period, is then developed. Correction factors are adopted to take into account variations in the structural characteristics, crowd morphology and return period. The correction factors, together with the reference acceleration, are used to determine the final response of the footbridge, for a given probability of load occurrence.

General information
Publication status: Published
Organisations: Department of Civil Engineering, Section for Structural Engineering
Contributors: Matteoni, G., Georgakis, C.
Number of pages: 360
Pages: 17-17
Publication date: 2010

Host publication information
Title of host publication: Advances and Trends in Structural Engineering, Mechanics and Computation
Publisher: CRC Press/Balkema
Keywords: footbridge, vertical vibration, load model, running, response spectrum
Electronic versions:
Matteoni_Georgakis_2010.pdf
Source: orbit
Source-ID: 266751

Shape modification of bridge cables for aerodynamic vibration control

In this paper, the viability of modifying cable shape and surface for the purpose of controlling wind-induced vibrations is examined. To this end, an extensive wind-tunnel test campaign was carried out on various cable sections in the critical Reynolds number region under both smooth and turbulent flow conditions. Shape modifications of a plain cylinder included waviness, faceting and shrouding. The aerodynamic damping of each section is evaluated by applying 1- and 2-DOF quasi-steady aerodynamic models, which allow for the prediction of regions of aerodynamic instability. Whilst the plain, wavy and faceted cylinders are found to suffer from either dry inclined galloping, "drag crisis" or Den Hartog galloping, the shrouded cylinder is found to be completely stable for all wind angles of attack, albeit with a slight increase in drag at traditional design wind velocities. The wavy cylinder is found to eliminate the risk of dry inclined galloping, with a reduction in lift fluctuations. Nevertheless, the particular cylinder is at risk of "drag crisis" instability. Finally, turbulent flow is shown to introduce a significant amount of aerodynamic damping by proving a more stable lift force over tested wind velocities.

General information
Publication status: Published
Organisations: Section for Structural Engineering, Department of Civil Engineering
Contributors: Kleissl, K., Georgakis, C.
Publication date: 2010

Host publication information
Title of host publication: Proceedings of SEMC, Cape Town, Sep. 2010
Electronic versions:
SEMC2010 paper.pdf
Source: orbit
Source-ID: 262681
The present work is motivated by a hanger vibration event on the Great Belt East Bridge, involving hanger ice accretion from March 27-31, 2001. The paper outlines a series of icing tests performed on a cylinder at the NRC Altitude Icing Wind Tunnel in March 2009 and the wind tunnel tests thereafter, leading to a description of the mechanism behind the hanger motional instability. Transmission line vibrations due to ice accretion have received considerable interest in recent years [1-5]. Although much work has been done on the wind-induced vibrations of bridge cables e.g. [6-8], little or no research on ice-accreted bridge cables exists. Figure 1 shows a typical section of ice accretion as has been found on a vertical hanger of the Great Belt East Bridge, with a diameter of approximately 115mm. This ice shape is not from the specific aforementioned vibration event, but it illustrates that a fairly uniform ice accretion can be generated on cylindrical cables. In order to investigate the nature of accretion, a set of wind tunnel tests were performed at varying temperatures and with varying levels of liquid water content. From these experiments, one ice shape similar to that of Figure 1 was selected. This was then used in the generation of a generalized ice profile. The generalized ice profile was selected so as to depict with a fair degree of representation the most commonly observed ice accretion on the Great Belt East Bridge. Subsequently, the generalized ice profile was manufactured by use of rapid prototyping. Next, a series of static wind tunnel tests were undertaken to determine the aerodynamic force coefficients of the rapidly prototyped hanger sectional model. Finally the aerodynamic force coefficients (drag, lift and moment), found from the static wind tunnel tests, were used to determine the potential for aerodynamic instability of the hanger through application of the quasi-steady theory developed by Gjelstrup et al. [9-10]. The application of the theoretical model yield regions of expected aerodynamic instability in which the observed vibrations of the Great Belt East Bridge hangers lie.
Design Specifications for a Novel Climatic Wind Tunnel for the Testing of Structural Cables

General information
Publication status: Published
Organisations: Section for Structural Engineering, Department of Civil Engineering
Contributors: Georgakis, C., Koss, H., Ricciardelli, F.
Publication date: 2009

Host publication information
Title of host publication: Proceedings of The 8th International Symposium on Cable Dynamics
Source: orbit
Source-ID: 247422

Drag coefficients of lattice masts from full-scale wind-tunnel tests
In this paper, the drag coefficients obtained from a series of full-scale section model wind-tunnel tests of several lattice mast configurations are presented and compared to those provided in Eurocode 3 and ESDU. The drag coefficients provided in Eurocode are conservative interpretations of 1:5 scale section model tests performed at the National Physics Laboratory and the National Maritime Institute in the UK in the 1970’s. ESDU provides velocity-dependent drag coefficients equivalent to those obtained from the same series of tests. In all cases, the mast legs and diagonals are comprised primarily of circular hollow sections, putting into question the validity of the scaled tests from the 70’s. The results of the full-scale tests show that the drag coefficients of the masts have lower values than those obtained from the scaled tests for turbulent wind and higher for winds with low turbulence.

General information
Publication status: Published
Organisations: Section for Structural Engineering, Department of Civil Engineering, Ramboll Group AS, Technical University of Denmark
Contributors: Georgakis, C., Støttrup-Andersen, U., Johnsen, M., Nielsen, M., Koss, H.
Publication date: 2009

Host publication information
Title of host publication: 5th European African Conference on Wind Engineering
Source: orbit
Source-ID: 243522

A NEW GENERAL 3DOF QUASI-STEADY AERODYNAMIC INSTABILITY MODEL

General information
Publication status: Published
Organisations: Section for Structural Engineering, Department of Civil Engineering, COWI AS
Contributors: Gjelstrup, H., Larsen, A., Georgakis, C., Koss, H.
Publication date: 2008

Host publication information
Title of host publication: 6th International Colloquium on Bluff Bodies Aerodynamics and Applications
Source: orbit
Source-ID: 208278

A preliminary experimental investigation into lateral pedestrian-structure interaction
This paper presents results from a preliminary experimental study on lateral human-structure dynamic interaction on footbridges using an instrumented platform. The platform has a natural frequency within the range of an average pedestrian and consists of a suspended concrete girder. With a length of 17 m and weight of 19.6 ton, the platform
provides a realistic comparison to an actual footbridge. Based on experiments with single pedestrians walking across the platform at resonance, the fundamental dynamic load factor is determined using only the recorded acceleration signal. Furthermore, tests were made with small groups of people to investigate their tendency to synchronise their walking to the motion of the platform. By analysing the recorded acceleration response and video data from the tests, the pedestrian pacing rate distribution and correlated pedestrian force have been identified and are presented herewith. Finally, the results from this study are compared to previous full-scale as well as section model measurements.

General information
Publication status: Published
Organisations: Section for Structural Engineering, Department of Civil Engineering, Ramboll Group AS
Contributors: Ingólfsson, E. T., Georgakis, C., Knudsen, A.
Publication date: 2008

Host publication information
Title of host publication: EURODYN 2008 : Proceedings of the seventh European conference on structural dynamics
Keywords: DLF, lateral vibration, Footbridges, instrumented platform
Source: orbit
Source-ID: 209136
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2008 › Research › peer-review

Seismic Performance of Multi-Span RC Railway Bridges
Presently, there is no clear method for determining the optimal railway bridge design for a particular ground type and expected seismic intensity. Four main types of RC bridge dominate the current multi-span railway bridge design trends – the Simply Supported Beam, Continuous Box-Girder (CBG), CBG with Lead Rubber Bearing (LRB) supports and the laterally fixed continuous deck (CRB) with LRBs. In this paper, the seismic performance of these four types is examined for varying ground types and seismic intensities. For the purposes of comparison, all of the bridges have five spans with identical span lengths and topography. Initially, typical bridge deck, pier and bearing configurations are chosen and analyzed through a series of nonlinear time-history analyses using synthetic accelerograms, in which plastic hinge formation is permitted. Next, an optimization of the bridge configurations is undertaken to increase the performance and reduce the overall bridge cost. Finally, an evaluation of the lifetime bridge costs are made assuming current prices, including costs relating to the damage associated with the expected seismic events. This is accomplished through the use of approximated damage states and fragility curves in relation to PGA. The cost comparisons clearly show that particular bridge types perform better than others economically for specific ground types and expected seismic intensities, even though in some cases they may be expected to suffer larger damages during their lifetime.

General information
Publication status: Published
Organisations: Section for Structural Engineering, Department of Civil Engineering, Pedelta S.L.
Contributors: Georgakis, C., Barrau, X.
Pages: 05-02-001
Publication date: 2008

Host publication information
Title of host publication: World Conference on Earthquake Engineering. Proceedings
Place of publication: Beijing, China
Vertical footbridge vibrations: details regarding and experimental validation of the response spectrum methodology

General information
Publication status: Published
Organisations: Section for Structural Engineering, Department of Civil Engineering, Coastal, Maritime and Structural Engineering, Department of Mechanical Engineering
Contributors: Ingólfsson, E. T., Georgakis, C., Svendsen, M. N.
Publication date: 2008

Host publication information
Title of host publication: Third International Conference FOOTBRIDGE 2008 : Footbridges for urban renewal
Keywords: Footbridge, experimental validation, crowd load, vertical vibration, response spectrum
Source: orbit
Source-ID: 219859
Research output: Chapter in Book/Report/Conference proceeding – Annual report year: 2008
Research › peer-review

Vertical Footbridge Vibrations: The Response Spectrum Methodology

In this paper, a novel, accurate and readily codifiable methodology for the prediction of vertical footbridge response is presented. The methodology is based on the well-established response spectrum approach used in the majority of the world's current seismic design codes of practice. The concept of a universally applicable reference response spectrum is introduced, from which the pedestrian-induced vertical response of any footbridge may be determined, based on a defined "event" and the probability of occurrence of that event. A series of Monte Carlo simulations are undertaken for the development of a reference response spectrum. The simulations use known statistical data for pedestrian and population walking characteristics to generate loads for a 50m long simply-supported bridge, with a fixed level of damping and a mean pedestrian flow rate of 1 pedestrian / sec. The response obtained from the reference spectrum is then modified to take into account actual span length, bridge damping, pedestrian pacing frequency, variation on mode shapes and predicted bridge-specific flow rates. Furthermore, the response is modified to account for a specific event return period. The concept of a cumulative event period is introduced and its implication on the calculation of footbridge response is discussed. Finally, a brief comparison is made between the theoretically predicted pedestrian-induced vertical response of an 80m long RC footbridge (as an example) and actual field measurements. The comparison shows that, unlike current codes of practice and other response-prediction approaches, the proposed methodology offers theoretical predictions within 7% of those experimentally measured.

General information
Publication status: Published
Organisations: Section for Structural Engineering, Department of Civil Engineering
Contributors: Georgakis, C., Ingólfsson, E. T.
Pages: 267-275
Publication date: 2008

Host publication information
Title of host publication: Footbridge 2008
Place of publication: Porto, Portugal
Editor: Caetano, E.
Source: orbit
Source-ID: 208922
Research output: Chapter in Book/Report/Conference proceeding – Annual report year: 2008
Research › peer-review

A Preliminary Investigation of the Hanger Vibrations on the Great Belt East Bridge

General information
Publication status: Published
Organisations: Section for Structural Engineering, Department of Civil Engineering, COWI AS
Contributors: Gjelstrup, H., Georgakis, C., Larsen, A.
Publication date: 2007
Cable Vibration due to Ice Accretions

On March 29, 2001, the Great Belt East Bridge exhibited large-amplitude hanger vibrations having elliptical orbits for wind speeds of between 16 – 18 m/s. Vibrational amplitudes were in the order of 2 m in the across-wind direction and 0.6 m in the along-wind. In this poster, a preliminary investigation behind the causes of this relatively isolated hanger vibration event on the Great Belt East Bridge is presented. Furthermore, a stability criterion for a 3DOF bluff body is proposed. One of the main assumptions of the investigation is that icy conditions may have contributed in some way to large hanger response by changing the cylindrical cross-sectional shape or partially changing the surface texture of the hangers. The change in shape or the surface texture has the effect of a change in the aerodynamic lift and drag coefficients in a certain Reynolds number range which in turn may lead to a form of “drag instability”. From the visual observations of the vibrations it is assumed that the aerodynamic moment coefficient is zero.
Full scale numerical analysis of high performance concrete columns designed to withstand severe blast impact

Polymer reinforced Compact Reinforced Composite, PCRC, is a Fiber reinforced Densified Small Particle system, FDSP, combined with a high strength longitudinal flexural rebar arrangement laced together with polymer lacing to avoid shock initiated disintegration of the structural element under blast load. Scaled experimental and numerical results of PCRC columns (200x200x1600mm) subjected to close-in detonation are presented in this paper. Based on these results and the use of geometrical scaling lows, a full scale column (800x800x6400mm) is designed and verified numerically to withstand 486.5 kg of PETN (85/15) High Explosives at stand off 1600 mm. Additionally, a LS-DYNA material model suitable for predicting the response of Polymer reinforced Compact Reinforced Concrete improved for close-in detonation and a description of the LS-DYNA multi-material Eulerian method for modeling the blast event is also presented in this paper.

Vertical footbridge vibrations: Towards an improved and codifiable response evaluation

An improved and codifiable footbridge response evaluation is presented herewith, in which peak vertical accelerations are provided as a function of load return period in the form of response spectra. To achieve this, a series of Monte Carlo simulations are employed to generate vertical loads induced by a "random" crowd that are subsequently used in linear timehistory analyses of the response of bridges with varying fundamental frequencies. The peak accelerations are presented as a function of return period and it is shown that the acceleration response due to a crowd is lower than $\sqrt{N}$ times the response of a single pedestrian, which is often referred to as a conservative estimate for crowds.
Experimental validation and calibration of pedestrian loading models for footbridges

Different patterns of pedestrian loading of footbridges exist, whose occurrence depends on a number of parameters, such as the bridge span, frequency, damping and mass, and the pedestrian density and activity. In this paper analytical models for the transient action of one walker and for the stationary action of an incoherent crowd of walkers will be presented, whose parameters have to be calibrated based on experimental tests. Results will be summarised of tests aimed at a statistical characterisation of the walking parameters and of the walking forces. In addition, results of tests performed on a model footbridge will be shown, aimed at setting the limits of applicability of the proposed models.

General information
Publication status: Published
Organisations: Section for Structural Engineering, Department of Civil Engineering, Mediterranea University of Reggio Calabria, University of Florence
Contributors: Ricciardelli, F., Briatico, C., Ingólfsson, E. T., Georgakis, C.
Number of pages: 1,407
Pages: 189-199
Publication date: 2006

Host publication information
Title of host publication: Experimental Vibration Analysis for Civil Engineering Structures
Editors: Cunha, A., Caetano, E.
Source: orbit
Source-ID: 205510
Research output: Chapter in Book/Report/Conference proceeding – Annual report year: 2007
Research: peer-review

Nonlinear dynamic of cable stays. Part 2: stochastic cable support excitation

In this paper, an extensive behavioural study of cable vibrations, induced by in-plane stochastic cable-stayed structural vibrations, is made. Finite element modelling (FEM) and analysis (FEA) is used to determine in-plane and out-of-plane cable displacements induced by stochastic cable end displacements. The effects of stochastic cable support displacements, with abrupt and gradual transients, are studied. Regions of large amplitude cable vibrations, induced by stochastic cable end displacements, are compared with those found from sinusoidal cable end displacements. The results show that, together with important similarities in cable response, there are also important differences in cable response between sinusoidal and stochastic cable support excitation. Differences in cable response amplitudes are found and discussed. It is also found that "cable-stiffening" occurs, for specific cable excitation parameters, as it does for sinusoidal cable support excitation, but to a lesser extent. Throughout the analyses, maximum cable stresses are calculated and, in some cases, are found to be near that required for cable material yielding.

Keyword: non-linear, mast, cable-stayed, parametric, cable, vibration, bridge, stochastic

General information
Publication status: Published
Organisations: University of Bristol
Contributors: Georgakis, C. T., Taylor, C. A.
Pages: 565-591
Publication date: 2005
Peer-reviewed: Yes

Publication information
Journal: Journal of Sound and Vibration
Issue number: 281
ISSN (Print): 0022-460X
Ratings:
Scopus rating (2005): SJR 1.162 SNIP 1.75
Web of Science (2005): Indexed yes
Original language: English
DOIs:
10.1016/j.jsv.2004.01.023
Source: orbit
Source-ID: 197422
Research output: Contribution to journal – Journal article – Annual report year: 2005
Research: peer-review
Nonlinear dynamics of cable stays. Part 1: sinusoidal cable support excitation
An extensive behavioural study of cable vibrations, induced by sinusoidal cable-plane structural vibrations, is presented. Non-linear equations of motion are formulated for a hanging cable with a small sag-to-span ratio. The effects of sinusoidal cable support displacements, with abrupt and gradual transients, are studied. Cable in-plane and out-of-plane displacements are generated through multiple shape-function analyses. Previously observed regions of large amplitude cable vibrations, in the excitation amplitude/frequency parameter plane and for sinusoidal cable end displacements, are verified and new regions of response instability are found. In addition, regions within the parameter plane are characterised as periodic, quasi-periodic or chaotic. The effects of changes in initial cable conditions are examined and differences in maximum displacement amplitudes are found and compared to those found from a zero-initial-condition sinusoidal support excitation. For specific excitation amplitude/frequency parameter pairs, ‘cable stiffening’ is observed. Throughout the analysis, maximum cable stresses are calculated and found to be less than those required for material yielding. The significance of a cable-support interaction is briefly discussed.
Keyword: non-linear, mast, cable stiffening, quasi-periodic, parametric, cable, chaotic, cable-stayed structures, bridge

General information
Publication status: Published
Organisations: Technical University of Denmark, University of Bristol
Contributors: Georgakis, C. T., Taylor, C. A.
Pages: 537-564
Publication date: 2005
Peer-reviewed: Yes

Publication information
Journal: Journal of Sound and Vibration
Issue number: 281
ISSN (Print): 0022-460X
Ratings:
Scopus rating (2005): SJR 1.162 SNIP 1.75
Web of Science (2005): Indexed yes
Original language: English
DOIs:
10.1016/j.jsv.2004.01.022
Source: orbit
Source-ID: 197421
Research output: Contribution to journal › Journal article – Annual report year: 2005 › Research › peer-review

Tuned Liquid Dampers for the New European Court of Justice, Luxembourg
As a consequence of their unique positioning and 3:5:1 plan ratio, the proposed twin 103m buildings of the latest expansion of the European Court of Justice (Luxembourg) led to the commissioning of a comprehensive set of wind-tunnel tests. Experimental testing and numerical analyses showed the buildings to be susceptible to unacceptably large wind-induced accelerations at the top levels. To mitigate these vibrations, a Tuned Liquid Damper (TLD) array is proposed and designed for both buildings. With an optimal design of the TLD array, total maximum reductions in top-level accelerations are found to be in the range of 35-40%, bringing tower accelerations below acceptable limits for human comfort. Experimental verification of the performance of the dampers is undertaken through 1:2 scale shaking table tests.

General information
Publication status: Published
Organisations: Section for Structural Engineering, Department of Civil Engineering, FORCE Technology
Contributors: Georgakis, C., Koss, H. H.
Pages: 228-231
Publication date: 2005
Peer-reviewed: Yes

Publication information
Journal: Structural Engineering International (SEI)
Volume: 15
Issue number: 4
ISSN (Print): 1016-8664
Ratings:
Scopus rating (2005): SJR 0.171 SNIP 0.373
Web of Science (2005): Indexed yes
Original language: English
DOIs:
Wind Engineering for the New European Court of Justice

In this paper, a description of the building aerodynamics studies for the new 4th extension of the European Court of Justice is undertaken. The investigations of the effects of the wind can be classified in two categories: those relating to the comfort of pedestrians in and around the complex and those relating to the overall wind loading and occupancy comfort of the structures. Unique to this arrangement are the twin 103m tall towers – slender and arranged in parallel with an aspect ratio of approximately 3.5:1. Pedestrian level wind climate studies were performed by using physical and numerical investigative techniques. In the assessment of human wind comfort conditions various approaches are discussed considering recent comparative efforts on a European level. An examination of the twin tower dynamic response to wind using Eurocode 1 showed tower accelerations to be below the chosen acceptable acceleration levels. Further dynamic time-history analysis of the towers, though, revealed higher than acceptable tower accelerations for specific wind directions. A response reduction system for the towers was developed in the form of Tuned Liquid Dampers (TLD) – the first known application of this system at this scale within Europe.

Comparison of Seismic Design Methods for Irregular RC Bridges

In this paper, the non-linear seismic response of an irregular 457m reinforced concrete (RC) box-girder bridge is examined in detail. The bridge was originally designed based on the current prevailing international design capacity philosophy, in which bridge strength and ductility capacities are designed to meet strength and ductility demands, as found from a response spectrum analysis. To determine the appropriateness of this design approach, a non-linear time-history analysis methodology is devised for the bridge. As part of this methodology, synthetic accelerograms are created, based on a site-specific response-spectrum, and used in non-linear time-history analyses of the bridge, in which ductile elements have been modelled using bi-linear hysteresis models. The results obtained from the linear and non-linear analyses are compared and significant deviations in load effects and ductility demands are found at key locations along the bridge. The significance of these deviations is discussed. Additionally, seismic performance enhancing bridge design alterations are also suggested.
The influence of cable-deck interaction on the seismic response of cable-stayed bridges

The natural frequencies of deck and local cable vibrations of cable-stayed bridges are in the same range, leading to the possibility of dynamic cable-deck interaction, while cables themselves exhibit significant geometric non-linearities. Bridge analyses often consider global bridge vibrations and local cable vibrations separately, ignoring any interaction, while previous studies of cable-deck interaction have often overlooked important aspects of the behaviour such as the influence of the cable on the deck, realistic levels of loading or the distribution of damping. In this paper, the influence of cable-deck interaction on the seismic response of cable-stayed bridges is examined in greater detail by considering the response of a simplified non-linear cable-deck model to earthquake loading. Responses from non-linear time-history analyses are compared with those from a linear analysis and from two other models considering the global and local cable vibrations separately. Significant interaction is apparent, including 'parametric' excitation of the cable due to end displacement at twice its natural frequency. However, this effect takes a long time to develop, and of greater relevance to earthquake loading is the converse non-linear effect of the cable on the deck. Also, greater dynamic cable tensions are caused by local cable vibrations than by global bridge vibrations, but the interaction appears to cause a slight reduction in the maximum total tension.

Keyword: cable-stayed bridges, cable dynamics, cable-deck interaction, geometric non-linearities, parametric excitation, seismic excitation

General information
Publication status: Published
Organisations: Unknown
Contributors: Macdonald, J. H. G., Georgakis, C.
Number of pages: 6,000
Publication date: 2002

Host publication information
Title of host publication: The Twelfth European Conference on Earthquake Engineering
Place of publication: London
Publisher: Elsevier
ISBN (Print): 978-0-08-044049-1
Source: orbit
Source-ID: 197423

ECOEST2/ICONS: Experimental study and perspectives of semi-active oleodynamic devices for seismic protection of structures

General information
Publication status: Published
Organisations: University of Naples Federico II, Unknown
Contributors: Serino, G., Occhiuzzi, A., Georgakis, C. T.
Publication date: 2001

Publication information
Place of publication: LNEC, Portugal
Publisher: LNEC
ISBN (Print): 972-49-1893-9
Original language: English
Source: orbit
Source-ID: 197435

Non-linear Analysis of Wind-Induced Cable-Deck Interaction

The natural frequencies of deck and local cable vibrations of cable-stayed bridges are in the same range, leading to the possibility of dynamic cable-deck interaction, while the cables themselves exhibit significant non-linearities. Bridge analyses generally use simple cable models and do not address these issues. Previous studies of cable-deck interaction have often overlooked important aspects of the behaviour including the influence of the cable on the deck, realistic amplitudes of deck displacements and the origins of damping, including aerodynamic damping. In this paper, the cable-deck interaction is modelled more fully by considering the response of a simplified non-linear cable-deck system to applied dynamic forces representative of wind buffeting. The model parameters are based on values for a typical cable-stayed bridge to assess the significance of the interaction effects, non-linearities and aerodynamic damping for practical cases.

Keyword: cable-stayed bridges; cable dynamics; cable-deck interaction; aerodynamic damping; geometric non-linearities;
Practical implementation of semi-active control through response-prediction algorithms

Research over the past several decades into semi-active control has provided useful insight into the practical applications of this type of control on actual structures. Hardware and software limitations, though, have made the implementation of such control very difficult. Time delays in both hardware and software make practical implementation differ greatly from that of theory. These delays, together with a prediction algorithm that may help overcome some of these, are presented in the current paper. The effectiveness of the prediction algorithm is tested analytically and experimentally using sine and random response waves.

Response Prediction Methods for Semi-Active Control of Structures

General information