Symposium on

The Mechanics of Slender Structures

MoSS 2010

21-23 July 2010

Programme

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Preface and Welcome

This CD-ROM of Proceedings contains abstracts and papers presented at the Symposium on the Mechanics of Slender Structures (MoSS2010) hosted by The University of Mondragon and held in San Sebastian (Spain) from 21st to 23rd July 2010 (website . http://www.mondragon.edu/MoSS2010/)

The conference has been organized in collaboration with the Applied Mechanics Group of the Institute of Physics and the Technical Committee on Vibration and Sound of the American Society of Mechanical Engineers.

It follows a one day seminar on *Ropes*, *Cables*, *Belts and Chains: Theory and Applications* and the MoSS2006 symposium (website: http://www.eng.nene.ac.uk/~conf2006/Symposium.htm) held at the University of Northampton in 2004 and 2006, respectively, and the MoSS2008 symposium held at the University of Maryland Baltimore County in 2008 (website: http://www.eng.nene.ac.uk/~moss2008/index.html).

The Organizing Committee welcomes all attending the MoSS2010 meeting and hopes that the delegates will find the technical programme both interesting and challenging.

Applications of slender structures include terrestrial, marine and space systems. Moving elastic elements such as ropes, cables, belts and tethers are pivotal components of many engineering systems. Their lengths often vary when the system is in operation. The applications include vertical transportation installations and, more recently, space tether propulsion systems. Traction drive elevator installations employ ropes and belts of variable length as a means of suspension, and also for the compensation of tensile forces over the traction sheave. In cranes and mine hoists, cables and ropes are subject to length variation in order to carry payloads. Tethers experiencing extension and retraction are important components of offshore and marine installations, as well as being proposed for a variety of different space vehicle propulsion systems based on different applications of momentum exchange and electrodynamic interactions with planetary magnetic fields. Furthermore, cables and slender rods are used extensively in civil engineering; in cable-supported bridges, guyed masts and long-span roofs of buildings and stadia. Suspended cables are also applied as electricity transmission lines. Chains are used in various power transmission systems that include such mechanical systems as chain drives and chain saws. Moving conveyor belts are essential components in various material handling installations. Other structures such as pipelines, plates, beams, mechanical linkages, and DNA structures also fall into this category.

The behaviour of these elements plays a significant role in the performance of the host structure and a holistic approach is needed in the analysis and design of the entire system. This meeting brings together experts from various fields: structural mechanics, thermo-mechanics, dynamics, electrodynamics, vibration and control, structural health monitoring, artificial intelligence, materials science and applied mathematics to discuss the current state of research as well as rising trends and direction for future research in the area of mechanics of slender structures. The event is aimed at improving the understanding of structural and thermo-mechanical properties and behaviour of slender structures. The presentations at the conference cover analytical, numerical and experimental research in various applications of slender structures.

The Organizing Committee gratefully acknowledges support received from the co-sponsoring institutions and would like to thank the authors for their hard work and high quality contributions.

Xabier Arrasate
The University of Mondragon

Stefan Kaczmarczyk
The University of Northampton

July 2010

Wednesday 21st July	
08:00 – 15:00	**Registration**
09:00 – 09:20	**Welcome and Introduction** Rector/ Vice-Chancellor; Mondragon Unibertsitatea, Spain
09:20 – 10:10 **Chair:** **Peter Hagedorn**	**Keynote Lecture 1: The dynamic stability of a moving oscillator on a long flexible structure** Andrei Metrikine; Delft University of Technology, The Netherlands **Abstract.** A benchmark model is considered in this paper to discuss the underlying physical mechanism of the dynamic instability of a moving vehicle on a long flexible structure. The model is composed of an infinitely long beam on elastic foundation and a moving two-mass oscillator. The variation of the mechanical energy of the moving oscillator over the period of its vibration is derived and used to interpret the stability diagram. It is shown that the instability is fully governed by the excitation of anomalous Doppler waves in the beam.
10:10 – 10:30	**Resonant response of axially-loaded structures** Lawrie Virgin; Duke University; USA **Abstract:** Tuning a musical string instrument typically consists of altering the tension, and thus frequency, of strings, in the audible range. Changing the length or material properties also changes the natural frequencies but not nearly as easily as changing the tension. If the string were able to withstand compressive forces then the range of frequency change could be extended to much lower frequencies. Elastic structural elements typically can withstand a degree of compressive axial loading. It is well-established that lateral stiffness can be strongly influenced by both tensile and compressive axial loading, and this is true for various beams, plates and shells [1]. Elastic buckling represents a complete loss of stiffness. However, this is limited by material nonlinearity on the one hand (where excessive tension may lead to yielding) and geometric nonlinearity on the other (where excessive compression may lead to buckling). This latter case is of most practical interest (specifically for slender structures), and is characterized by the stiffness of a structure dropping to zero, and thus no further load-carrying capacity is possible without gross deformation and perhaps catastrophic failure. The *weight* of slender elements in a gravitational field leads naturally to axial loading, and can even cause slender structures to buckle under their own (self) weight [2]. In this case, the axial load is distributed over the length of the member. For distributed tensile forces the limiting case for a slender structure in a gravitational field is the hanging chain. In most of these various cases the lowest natural frequency of small-amplitude vibrations typically drops to zero as stiffness decreases, and this feature has been exploited for nondestructive testing purposes [3]. This paper focuses attention on a number of features associated with the vibration of axially-loaded slender structures. Both tensile and compressive effects are studied and the latter introduces the potentially important influence of buckling. The difference between constant and uniformly varying axial loading is highlighted [4]. Post-buckling, damping, initial geometric imperfections are important extensions to the basic theory, which is briefly described in terms of beam elements. The extent to which the basic results can be applied to more complicated structures such as frames and plates is also explored. Finally, forced vibrations are also considered in which axial loading profoundly influences the phenomenon of resonance. Changing the natural frequency and hence resonance conditions of a structure allow a degree of *tuning*, i.e., a useful property in a number of applications including vibration isolation and energy harvesting.

10:30 – 10:50	**Nonlinear Experimental and Numerical Analysis of a Highly Deformed Riser** Sophia Santillan; United States Naval Academy; USA Lawrie Virgin; Duke University; USA **Abstract.** This paper models a slender, flexible structure used as a drill string or riser in the offshore oil and gas industry that connects the well-head with a floating control vessel. These systems are used in deep-water drilling applications and present considerable design challenges due to their extreme flexibility and susceptibility to buckling and vibration. Two typical configurations are used [1], with a common feature involving the attachment of a buoy designed to relieve some of the axial forces acting on the riser, especially at the attachment points. Previous work by the authors studied numerical results of small-amplitude vibrations and two other equilibrium configurations using parameter values that closely resemble the full-scale application [2]. Here, two new configurations are considered, and experiments are designed and conducted to verify these results.
10:50 – 11:20	**Coffee / Tea**
11:20 – 11:40 **Chair:** **José M. Abete**	**Damage Detection in Gas Pipelines by Remote Impact Measurement** Jack Hale, O A Olugboji; Newcastle University; UK **Abstract.** A technique is described for reconstructing the source of a pressure pulse propagating through a gas filled pipe from measurements of the attenuated and distorted pulse measured remotely from the source. The DSP techniques of digital filtering and deconvolution are described as applied to this application, and experimental results using these techniques are given. It is shown that a fair reconstruction is possible, but that a better reconstruction requires the use of inverse methods that take account of the non-linearity of the system.
11:40 – 12:00	**Corrugation Development on Beam under Passage of Rolling Disk** Yoshiaki Terumichi; Sophia University; Japan **Abstract.** The present paper proposes modeling and formulation for a numerical simulation of corrugation development on a flexible beam, which is regarded as a rail, under the passage of a rolling disk, which is regarded as a wheel. The planar motion of the beam is modeled using the absolute nodal coordinate formulation. A point contact is assumed for the coupled motion of the disk and the beam. Furthermore, measuring the total slip between the disk and the beam using the constraints of no slip, in the case of no slip in the overall motion, the contact patch is considered for the calculation of the amount of wear. In the contact patch, despite the no-slip condition in the overall motion, the slip and adhesion area are distributed, and the creep force is calculated. The surface profile of the beam is calculated and stored during the passage of the rolling disk. Numerical results are presented, and the mechanism of corrugation development is discussed, taking note of the wavelength of the corrugation. The efficiency and validity of the proposed approach are also verified.
12:00 – 12:20	**On the oscillations of an elastic structure with a periodically time-varying mass** Wim T van Horssen, Alexandr V. Pischanskyy, Dhiretjh Sewdoelare; Delft University of Technology, The Netherlands **Abstract.** In this paper the forced vibrations of an elastic structure with a time-varying mass will be studied. A single degree of freedom oscillator equation and a tensioned-beam equation will be introduced as simple model equations to describe the rain-wind induced vibrations of cables. Not only solutions of these equations will be constructed, but also stability properties for the forced vibrations will be presented for various parameter values.

12:20 – 14:00	**Lunch**
14:00 – 14:50 **Chair:** **Weidong Zhu**	**Keynote Lecture 2: Tensorial Deformation Measures for Flexible Joints** Olivier Bauchau; Georgia Institute of Technology, USA **Abstract.** Flexible joints, sometimes called bushing elements or force elements, are found in all multibody dynamics codes. In their simplest form, flexible joints simply consist of sets of three linear and three torsional springs placed between two nodes of a multibody system. For infinitesimal deformations, the selection of the lumped spring constants is an easy task, which can be based on a numerical simulation of the joint or on experimental measurements. If the joint undergoes finite deformations, identification of its stiffness characteristics is not so simple, specially is the joint is itself a complex system. When finite deformations occur, the definition of deformation measures becomes a critical issue. Indeed, for moderate deformation, the observed nonlinear behavior of materials is partly due to material characteristics, and partly due to kinematics. This talk focuses on the determination of proper finite deformation measures for an elastic body of finite dimension. In contrast, classical strain measures, such as the Green-Lagrange or Almansi strains, among many others, characterize finite deformations of infinitesimal elements of a body. It is argued that proper finite deformation measures must be of a tensorial nature, i.e., must present specific invariance characteristics. This requirement is satisfied if and only if deformation measures are parallel to the eigenvector of the motion tensor. It will be shown that these deformation measures accurately capture the kinematics of flexible joints for rather large motions. Implications to the mechanics of slender structures will be outlined.
14:50 – 15:10	**Free Vibration Analysis of Kirchoff Plates with Damaged Boundaries by the Chebyshev Collocation Method** Eric A. Butcher and Ma'en Sari, New Mexico State University; USA **Abstract.** This paper presents a new numerical technique for the free vibration analysis of slender Kirchoff plates with both mixed and damaged boundaries. For this purpose, the Chebyshev collocation method is applied to obtain the natural frequencies of Kirchoff plates with damaged clamped and simply supported boundary conditions. The damaged boundaries are represented by distributed translational and torsional springs. The boundary conditions are applied to the boundary points and their adjacent interior points, and are coupled with the governing equation to obtain the eigenvalue problem. Convergence studies are carried out to determine the sufficient number of grid points used. First, the results obtained for the undamaged plate with mixed boundary conditions are verified with previous results in the literature. Subsequently, the results obtained for the damaged Kirchoff plate indicate the behavior of the natural vibration frequencies with respect to the severity of the damaged boundary. Specifically, the change in the frequencies can be an indicator of the amount of boundary damage. This analysis can lead to an efficient technique for structural health monitoring of structures in which joint or boundary damage plays a significant role in the dynamic characteristics.

15:10 – 15:30	**Embedded Magnetostrictive Particulate Sensors in Composite Laminates** Oliver J. Myers, George Currie, Jonathan Rudd, Dustin Spayde; Mississippi State University, USA **Abstract.** Defects in adhesive bonding of several composite structures are difficult to detect because of the nonconductive and paramagnetic properties of composite materials. Also, defects introduced by fatigue, cracking and stresses are difficult to recognize due the nature of the material. Timely detection of delamination defects in composite parts can lead to improved reliability. This research illustrates the detection and analysis of delamination damage in carbon fiber laminate beams using a single layer of magnetostrictive particles (MSP). Magnetostrictive particles, embedded in the host structure undergo larges changes in magnetization intensity when the surrounding host structure experiences mechanical degradation. Combined magnetostrictive transduction of magnetic energy and reverse magnetostrictive transduction of mechanical electrical energy, known as the Villari effect, are explored. The sensor, composed of concentric excitation and sensing coils, is scanned over the entire structure. The excitation coil is used to generate a carrier magnetic field whereas the pickup coil acts as an induction that senses change in the magnetic field. Analytical models are developed to ensure the magnetostrictive materials are minimally intrusive. Numerical models are incorporated to model the magneto-mechanical coupling of the magnetostrictive materials as well as the magneto-mechanics of the embedded material in the composite structure. Non-destructive evaluation scanning experiments were conducted with various shapes and sizes of damages introduced into carbon fiber reinforced polymeric composite structures. The results demonstrate high potential for MSP as a low-cost, non-contacting, and reliable sensor for non-destructive evaluation of composite materials.
15:30 – 16:00	**Coffee / Tea**
16:00-16:20 **Chair:** **Xabier Arrasate**	**Dynamics of the Micro-Resonator Driven by Electrostatic Combs Based on Global Modes** Mitao Song, Dengqing Cao; Harbin Institute of Technology, China **Abstract.** The nonlinear dynamical behavior of micro comb-drive resonator under superharmonic excitation is investigated. The mathematic model that describes the dynamics of a micro-resonator is established in terms of a set of partial differential equations and ordinary differential equations. The global linear modes are used to discretize the established mathematic model using the Galerkin procedure. Numerical results show that the geometric nonlinearity has significant effects on the dynamical responses of the system in the case of third superharmonic resonance. In comparison with the numerical results obtained from the system with the first three modes, the one-degree-of-freedom nonlinear system has very good precision to represent the original system in the case of analyzing the dynamics of micro-resonator with certain parameters under third superharmonic excitation.

16:20-16:40	**Implanted Medical Wire Rope Bending Fatigue at 0<R<1** Charles Wilson; Medtronic, Inc., USA **Abstract.** The fatigue reliability of electrical conductors in implantable cardiac leads is a factor in the overall reliability of pacing and defibrillation lead systems. Therefore, the bending fatigue performance of these conductors can drive design decisions and help predict the performance of leads implanted in patients. Recently, a new test was developed to determine the bending fatigue performance of wire rope conductors outside of the lead system. The test utilizes post bifurcation buckling of a clamped-clamped beam, aka the clamped elastica, allowing the samples to bend in free space without the influence of test fixturing. The slenderness ratio for this test is approximately 400, which meets the criteria to be considered a slender structure. The cyclic fatigue conditions of the tests are determined based on the curvature measured at the midspan of the samples. The cycles to fracture data is plotted and fit with regression techniques using an equation form based on an adaptation of strain-life fatigue theory. The test is designed to create fractures at several curvature amplitude severities so that an experimental fatigue endurance strength curve for these wire rope conductors can be established. The testing is conducted at a ratio of min to max curvature between 0.3<R<0.7.
20:00	**Informal Dinner**

Thursday 22nd July	
08:30 – 12:00	**Registration**
09:00 – 09:50 **Chair:** **Yoshiaki Terumichi**	**Keynote Lecture 3: Mechanical Modelling of Lift Slender Structures** Ignacio Herrera; University of Extremadura, Spain **Abstract.** The mechanical performance of a lift structure represents a complex task and forms an important step in the elevator system design procedure. In this approach first the mechanical characteristics of elevator components were identified experimentally. It was found that the response was highly influenced by the mechanical properties of the suspension means, guiding system and, surprisingly, by the mass and damping and stiffness characteristics of passengers. The stiffness and damping coefficients in the vertical direction based on a single degree of freedom model of the individual components were found suitable for mechanical characterization of the elevator system. The dynamic lift response is very sensitive to these coefficients. An experimental procedure, based on a two degrees of freedom model, is proposed to quantitatively determine the passenger's stiffness and damping coefficients exposing the human bodies to a very simple and fast vibration test. A six degree of freedom of a lift system using the identified stiffness and damping characteristics of the components was developed. The model was implemented in the MSC Visual Nastran simulation environment and the response during a typical returned elevator trip was determined. The simulation results demonstrated the influence of various excitation inputs such as torque ripple and impact forces in ride quality of the elevator. Furthermore an efficient algorithm to simulate the transient response of the elevator was implemented in MATLAB. The proposed methodology and the results discussed in this paper will be used as benchmarks for further work to develop a software simulation tool for assessing the mechanical behavior of elevator systems.
09:50 – 10:10	**Deformation and Vibration Analysis of Elevator Traveling Cable** Seiji Watanabe, Masahiro Ishikawa; Mitsubishi Electric Corporation, Japan **Abstract.** The elevator installed in high rise buildings needs a long traveling cable for its operation. Even though such a long cable is required, the shaft space is limited and the clearance between elevator devices and cable is very narrow. As the elevator also runs faster in such buildings, the cable might induce large lateral vibration during a running condition. Therefore, it is very important to evaluate the cable suspension shape and vibration in advance. In this paper, a simplified two-dimensional cable model is proposed. The model is composed of divided masses and springs, which can include the gravity effect and bending stiffness. As temperature variation affects the cable shape, the cable physical parameters are expressed by a function of temperature. Several experiments of static and transient conditions are compared with the simulation results, so that the proposed simulation model is validated for the cable optimal design.

10:10 – 10:30	**Dynamics of a Slack Cable with Bending Stiffness with Application to Elevator Traveling and Compensation Cables** Weidong Zhu, Hui Ren, Chuang Xiao; University of Maryland BC, USA **Abstract.** A nonlinear, planar model of a slack cable with bending stiffness and arbitrarily moving ends is developed. The model uses the slope angle of the centroid line of the cable to describe the motion of the cable, and the resulting integro-partial differential equation with constraints is derived using Hamilton's principle. A new method is developed to obtain the spatially discretized equations, and the Baumgarte stabilization procedure is used to solve the resulting differential-algebraic equations. The model can be used to calculate the equilibria and corresponding free vibration characteristics of the cable, as well as the dynamic response of the cable under arbitrarily moving ends. The results for an equilibrium and free vibration characteristics around the equilibrium are experimentally validated on a laboratory steel band. The methodology is applied to elevator traveling and compensation cables. It is found that a vertical motion of the car can introduce a horizontal vibration of a traveling or compensation cable. The results presented are verified by a commercial finite element software. The current method is shown to be more efficient than the finite element method as it uses a much smaller number of elements to reach the same accuracy. Some other interesting features include the condition for a traveling or compensation cable equilibrium to be closest to a natural loop, and a direct proof that the catenary solution is unique.
10:30 – 11:00	**Coffee / Tea**
11:00-11:20 **Chair:** **Wim van Horssen**	**Dynamic Behavior of Prismatic Bars with Partially Stiff Ends Under Movable Actions** Juan Jose Jimenez de Cisneros y Fonfría, Juan de Dios Carazo Álvarez, Daniel Carazo Álvarez; Universidad de Jaén, Spain **Abstract.** The dynamic behaviour of a structure under a movable load depends on multiple factors, as the properties of the material or the geometrical characteristics. Amongst the more significant factor are the boundary conditions of the system, which in prismatic bars are the joints of the ends. The particular case of a semi-rigid support (with restrictions as lineal spring for the vertical displacement and as torsion spring for the rotation) follows the real description of the conditions present in a great number of structures. As examples: metallic beams with screwed joins without strengthening, or the case of bridges where the iteration soil-structure wants to be taken into account. During the present research, the bases of the system to be modelled are described, the particular analytical solution for partially stiff ends is obtained, and the results are compared to those achieved by the finite elements method.

11:20 – 11:40	**The Responses of Long Moving Vertical Ropes and Cables Subjected to Dynamic Loading Due to the Host Structure Sway** Stefan Kaczmarczyk; The University of Northampton, UK Radoslaw Iwankiewicz, Hamburg University of Technology, Germany Yoshiaki Terumichi; Sofia University, Japan **Abstract.** Long moving vertical ropes and cables are used in tall slender engineering structures. For example, in high-rise buildings and towers they are employed as a means of car and counterweight suspension and for compensation of tensile forces over the traction sheave in traction drive elevators. An adverse situation arises when the host structure is excited near its fundamental natural frequency and sways harmonically at low frequencies. This often results in a passage through resonance conditions in the rope system when the slowly varying natural frequencies of the ropes approach the frequency of the inertial load resulting from the structure sway. The nature of such a loading is usually nondeterministic and it is necessary to apply stochastic models to analyze the dynamic responses of the ropes. In this paper a model to describe the lateral dynamic behaviour of a vertical moving rope hosted in a tall slender structure is developed. The model takes into account the fact that the longitudinal elastic stretching of the ropes is coupled with their transverse motions which results in cubic nonlinear terms. The mathematical model comprises nonstationary nonlinear ordinary differential equations. Taking into account the fact that the motion of the structure can be represented as a narrow-band process mean-square equivalent to the harmonic process, equations for the second- and higher-order joint statistical moments are obtained with the aid of Itô differential rule. Due to the non-linearities the moment equations form a system of an infinite hierarchy which needs to be truncated at some level. The technique of cumulant - neglect closure (CNC) is proposed in order to implement the truncation procedure and to treat the system numerically.
11:40 – 12:00	**Development of a Simplified Wire Rope Model and Application to a Traction Sheave-Rope Contact** Rafael Rodriguez, M. Laspalas, M.A. Jiménez, A. Gomez; Instituto Tecnológico de Aragón, Spain **Abstract.** Wire ropes are widely employed in many industrial applications, for instance acting as a structural element in bridges, or transmission element in a lift. Their strength and functional life is determined by a large number of factors: materials, coverings, diameters of the wires, wire and strand configurations, diameter of the pulley, etc. The wear durability and fatigue life of both the rope and the pulley depend strongly on the stresses generated between the different wires and the sheaves with which they interact. In order to initiate the development of a numerical tool to analyse wire ropes in detail a simplified finite element model has been created to simulate the contact between the rope and the sheave of a traction pulley of a lift. Due to the high number of wires interacting, some simplifications are required in order to achieve computationally efficient models. Such simplifications are based on a multiscale simulation approach, where the properties of an individual strand are extracted through simulations. With these properties a transversely isotropic material is approximated, which feeds a continuum strand model. This methodology is applied to the simulation of the sheave – wire rope contact under static tension, allowing the prediction of the contact stress levels due to the contact of individual wires taking into account the global stiffness of the wire rope.

12:00 – 12:20	**Influence of the Bending Stiffness on the Contact Force and Sheave** Thomas Kuczera, Christian Vorwerk; University of Stuttgart, Germany **Abstract.** If a running rope is bent over a sheave, the line contact pressure (normal force between rope and sheave) shows a peak when the rope enters onto or runs off the sheave. This peak can reach up to 4 times the average line contact pressure depending mainly on rope construction (bending stiffness), rope force and ratio of diameters between rope and sheave [1]. At the moment the effect of different rope constructions, especially the bending stiffness of the rope, on the dimension of the peak of the line contact pressure is unknown.
12:20 – 14:00	**Lunch**
14:00 – 14:50 **Chair:** **Ignacio Herrera**	**Guest Lecture : The lift and the Environment** Rafael Macía; OTIS, Spain **Abstract.** The present high levels of energy consumption are causing important changes in the Earth climate. This fact can be seen in the progressive environmental degradation caused, among other agents, by the global warming. To try to minimise the problem the possible alternatives are to stop the countries development (nearly impossible), to decrease the level of life in the developed world (not accepted), to increase the use of “green energies” (very complicated), or to reduce the energy consumption by increasing the energetic efficiency of the general means and equipment (possible and feasible). The world is looking for solutions and different sectors as plants, buildings, traffic, transportation, heating and air conditioned, lighting, isolation, etc. are always considered. Nevertheless lifts, that suppose a significant rate of energy consumption, are not taken into consideration in the regulations in force. The lecture makes a fast overview of: - The history of lifts. - General aspects and key statistics’. - Main differences between the conventional and the “Green or New Generation Lifts”. - Economical study of the total lifts or modernisation packages change (definition of Green equipment, savings and over costs). - Regulation on going. A vision of the lifts of the future.

14:50 – 15:10	**A Simulation Model of the Vertical Dynamics of an Elevator System** Xabier Arrasate; Mondragon Unibertsitatea, Spain Stefan Kaczmarczyk; The University of Northampton, UK José M. Abete; Mondragon Unibertsitatea, Spain **Abstract.** The drive system is a key component of an elevator installation that supplies energy into the system, coupling the car-rope and the counterweight-rope subsystems. However, it often becomes a source of excitation that is responsible for vibrations that compromise the car ride quality. In this paper a non-stationary distributed-parameter model describing vertical dynamics of an elevator system that accommodates the drive machine, the car, the counterweight and the suspension ropes has been developed. The model is used to analyze the influence of the drive machine on the elevator system performance. The dynamic behaviour is described by a set of partial differential equations. Those are discretized by expanding the vertical displacements in terms of the linear mode shapes to obtain a set of ordinary differential equations. The mode shapes correspond to a system composed of three masses constrained by a suspension rope. The discrete model is then solved numerically in Matlab-Simulink using parameters of a real installation. The numerical simulation results predict transient resonance phenomena in the system.
15:10 – 15:30	**Horizontal Vibration of Car in the Flexible Suspension System of Elevator** Peng Zhang; State Key Lab of Mechanical System and Vibration, China Changming Zhu, Jihu Bao; Shanghai Jiao Tong University, China **Abstract:** In this paper, the methods of continuum dynamics and generalized Hamilton principle are used to model the forced horizontal vibration of flexible elevator hoisting system. Then, the theoretical model is solved with numerical methods. At last, the horizontal vibration of elevator car is analyzed during the period of motion by responding the excitation functions arising from the uneven surface of guide rail. According to the simulation results, the horizontal vibration of elevator car is affected not only by the uneven surface of guide rail but also by vibration of hoisting rope.

15:30 – 15:50	**Initial Steps in the Definition of Thermoplastic Polyurethane Elastomer /Cast Iron Contact Model by Finite Element Method** Luis Á.Bartolomé, W. Tato, M. A. Urchegui, J. A. Hernández, S. J. Portolés; Mondragon Unibertsitatea, Spain **Abstract.** Since years the elevator sector is being undertaken the downsizing components (motors, sheaves...) to gain space in the systems. Due to the reduction of sheaves diameter, metallic ropes with polymeric coatings are being employed to get a significant degree of adherence between rope and sheave. There are critical gaps in knowledge about the contact behavior of such coated ropes over sheaves. Therefore the development of contact models for these systems is essential. In this work the contact pair consists in thermoplastic polyurethane elastomer (TPU) and cast iron, which are employed in the vertical transport sector. Finite element method (FEM) is a suitable numeric method to simulate an elastomer-metal (TPU/cast iron) contact. But to use FEM, a material behavior model for TPU and a friction model must be implemented in the calculations. In this paper, firstly a bibliographical review of (1) hyperelastic models for elastomers, (2) the experimental tests to fit this material models and (3) friction models for polymers, especially for elastomers, are presented. Finally the derived conclusions from the tests carried out to obtain the material behavior and friction models for TPU-cast iron contact are detailed.
15:50 – 16:10	**Tea**
19:00	**Harbour Cruise**
20:30	**The Conference Banquet**

Friday July 23	
08:30 – 11:00	**Registration**
09:00 – 09:50 **Chair:** **Jack Hale**	**Keynote Lecture 4: Advances in Understanding Stay Cable Vibration** Nicholas P. Jones; Johns Hopkins University, USA **Abstract.** Cable-stayed bridges have frequently exhibited large-amplitude vibrations of the main stays, frequently associated with the simultaneous occurrence of wind and rain. These vibrations have been of concern because they potentially induce fatigue in the cables and cable anchorages. Early research on excitation mechanisms had generally been conducted using wind tunnels, and several distinct aerodynamic mechanisms were proposed. While considerable progress has been made in understanding and mitigating these vibrations, the state of the art has still not enabled the prediction of field behavior based on a set of supplied parameters, nor does a plausible, fully accepted model exist for the phenomenon. This presentation will summarize recent research efforts that have attempted to advance the state of understanding of this complex fluid-structure interaction problem. Both early efforts and recent investigations – primarily based on the collection and interpretation of comprehensive full-scale data – will be considered. In presenting these perspectives, focus will be placed on the use of a combined approach comprising observation, full-scale and laboratory (wind tunnel) investigations, analysis, and computational tools to develop understanding of aspects of this phenomenon and its mitigation, with it often being necessary to question past assumptions or assertions on the part of researchers and designers. In both understanding of the basic phenomenon, as well as in understanding the performance of mitigation systems, it became evident that preconceived notions about performance and assumptions in some instances clouded rather than aided the advancement of understanding. The overall goal of these efforts has been to better understand the mechanics of stay-cable vibration at a more fundamental level and enabling the recommendation of more effective and economical mitigation strategies.
09:50 – 10:10	**Stability analysis of taut strings carrying a moving mass** Angelo Luongo; University of L'Aquila, Italy Giuseppe Piccardo; University of Genoa, Italy **Abstract.** Oscillations induced by a moving mass on a taut string are studied. A linear continuum model is formulated, and both a standard Galerkin technique and a perturbation method are used to tackle the problem. This appear in the form of a parametrically excited system, in which the excitation frequency is related to the velocity of the travelling mass. The perturbation analysis permits to detect all the existing parametric excitation conditions of the mass-string system, potentially leading to instability phenomena in which single modes are involved, or several modes interact. In particular, the occurrence of summed or difference combination resonance, which lead to unstable or stable responses, respectively, has been identified. Preliminary analyses, devoted to a specific instability domain, present the accuracy of the perturbation solution compared to direct numerical integrations of the discrete equations of motion.

10:10 – 10:30	**Nonlinear analysis of slender arched footbridges against wave loads** Lluis Candini; Natividad Pastor, Alfredo Arnedo; Sener Ingeniería y Sistemas S.A. / Universitat Politècnica de Catalunya, Spain **Abstract.** Structural design of footbridges with spans up to 55 m and subjected to strong wave loads acting mainly in upwards and horizontal direction has been carried out. To resist these loads, an arched structure with tubular steel members was studied, consisting of two main chords joined by struts and diagonals and with a sliding support and a tension cable. Structural behavior of these arches is nonlinear: for downwards loads the cable is tensioned and the chords compressed whereas for upwards loads the cable gets compressed and does not work. Moreover, if sliding support reaches its maximum allowable displacement, the walkway will block and work as a fixed arch in both ends. Besides, global buckling due to the compression in the chords must be prevented because the arches are quite slender. After an initial linear analysis in steps, a nonlinear analysis of one arch was carried out with Abaqus FE software using one-dimensional FE elements. Nonlinear material was considered. Sliding support was modeled with a nonlinear connector allowing the blocking of the arch. For the nonlinear buckling analysis, two relevant buckling modes were considered as initial imperfection. The analysis showed how the structure was able to withstand the design loads.
10:30 – 11:00	**Coffee**
11:00 – 11:20 **Chair:** **Lawrie Virgin**	**Extremely Large Telescopes: Dynamics, Active Optics, Scale Effects** André Preumont, R Bastaits, G. Rodrigues; Université Libre de Bruxelles, Belgium **Abstract.** This paper is devoted to a most challenging problem of precision mechatronics: the active optics of future large telescopes (with primary mirrors of up to 40 m). The primary mirror of such a telescope involves up to nearly 1000 segmented mirrors independently controlled, 3000 position actuators and 5600 edge sensors. The overall wave front accuracy is of the order of 20 nm. The first part of the paper examines the modelling and the control strategy for active optics. The model has a moderate size due to the separation of the quasi-static behaviour of the mirror (primary response) from the dynamic response (secondary, or residual response). The control strategy considers explicitly the primary response of the telescope through a Singular Value Decomposition (SVD) controller. The second part of the paper addresses the scaling laws that allow extrapolating the results obtained with existing telescopes to future ones, and the most relevant parameters are highlighted.
11:20 – 11:40	**Time History Finite Element Modelling of a Vibrating Transmission Line Conductor** Sébastien Langlois, Frédéric Lévesque, Frédéric Légeron; Université de Sherbrooke, Canada **Abstract.** For overhead transmission lines, aeolian vibrations are the most common cause of fatigue failure of conductors. Because aging of the network is a major concern to utilities, knowledge of the phenomena causing conductor failures is essential for optimizing the reliability of the network. A common method for preventing failures due to aeolian vibrations is to install dampers on the conductors. This paper presents a numerical method that includes a precise representation of the conductor deformed shape. This model is a necessary step towards an adequate modelling of the complete conductor-damper system. The numerical model was developed using a time history finite element method. If the equivalent bending stiffness of the conductor is properly evaluated, the proposed method correctly predicts the behaviour of a vibrating conductor on laboratory spans. The model shows the characteristics associated with both transient and permanent responses of the conductor. The dynamic response of the model shows the relationship between the antinode amplitude, the peak-to-peak bending amplitude conventionally measured at 89 mm from the span extremity, and the variation of curvature near span end. These parameters are useful for studying conductor vibration and for linking levels of vibration to conductor fatigue life data. Finally, the possibility to include variable bending stiffness in the model is analyzed.

11:40 – 12:00	**Contact Mechanics Based Fatigue Indicator for Overhead Conductors** Frédéric Lévesque, Frédéric Légeron; Université de Sherbrooke, Canada **Abstract.** Aeolian vibrations are a cause of fretting fatigue in overhead conductors at contact points at or near supports. This damaging process involves contact mechanics. The geometry of the support is also an important factor. Actual fatigue indicators used by the industry do not take into account these key parameters. This fact halves the effectiveness of those tools in improving the reliability of transmission lines or optimising their design. A fatigue indicator based on a simplified representation of the critical contact areas and the use of a critical plane crack initiation criterion is proposed here. Generally elliptical contact areas are represented by equivalent circular ones. The yielding of the interface is taken into account. The Fatemi-Socie critical plane crack initiation criterion is used to predict fatigue life. The fatigue indicator shows good agreement with fatigue data.
12:00 - 13:30	**Lunch**
13:30 - 14:30 **Chair:** **Stefan Kaczmarczyk**	**Keynote Lecture 5: The space elevator and our future** Bryan Laubscher; Odysseus Technologies, LLC, USA **Abstract.** The Space Elevator is a radical concept for accessing space. Indeed, the Space Elevator may be the ultimate slender structure. Its earliest beginnings date to the writings of Tsiolkovski. The first publication occurred in 1960 in the Soviet Union's paper, Pravda. This presentation begins with the conceptual design which comprises a 100,000 km long carbon nanotube ribbon stretching from the surface of the earth out into space. Vehicles access space by ascending high on the ribbon and either dropping into orbit around Earth or being thrown beyond Earth orbit to other destinations in the solar system. The challenges of building the elevator are outlined and solutions for these problems are mentioned. The promise of the Space Elevator will be discussed in some detail as the elevator is expected to dramatically decrease the cost of accessing space. The primary challenge, the material and its properties required to build the Space Elevator, will be examined in some detail.
14:30 - 15:20	**Discussion Forum:** Rrising trends and directions for future research in the area of mechanics of slender structures
15:20 – 15:30	**Close of Proceedings**