Symposium on

Mechanics of Slender Structures

MoSS 2006

28-29 September 2006

Programme and Abstracts

THE UNIVERSITY OF NORTHAMPTON

Institute *of* Physics
Stress and Vibration Group

I MECH E

INVEST Northamptonshire
THE CENTRAL GROWTH LOCATION

Research Innovation Design TRIaD

LEIA
Lift and Escalator Industry Association

BGA
British Gear Association

http://www.eng.nene.ac.uk/~conf2006/Symposium.htm

Welcome and Preface

The programme contains papers presented at the Symposium on the Mechanics of Slender Structures (MoSS 2006) held at The University of Northampton, U.K. from 28th to 29th September 2006. The event forms a part of the Inaugural Lift Engineering School 2006-07 held annually by the Lift Technology Section in the Division of Engineering. The symposium has been organized in collaboration with the Stress and Vibration Group of the Institute of Physics (http://groups.iop.org/SV/) and follows a seminar held in Northampton during the Inaugural Lift Engineering School in 2004 ("Ropes, Cables and Chains: Theory and Applications"; details are available from the seminar website: http://groups.iop.org/SV/AE/Ropes.htm). The event is co-sponsored by Invest Northamptonshire, the Lift and Escalator Industry Association, ThyssenKrupp Research Innovation and Design (TRIaD) Product Planning Group, the British Gear Association and the Institution of Mechanical Engineers.

The Organizing Committee welcomes all attending the MoSS 2006 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.

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, and materials science 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 Proceedings contains papers covering analytical, numerical, and experimental research into the mechanics of ropes, cables, tethers, chains, yarns and fibres as well as their interactions with the host structure in various engineering applications.

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. The organizers are very grateful to the members of the Scientific Committee for their time and effort in reviewing the papers. Last but not least special thanks are due to Phillip Andrew for his considerable input in the preparation of the Proceedings CD-ROM.

Stefan Kaczmarczyk
Northampton
September 2006

Wednesday 27th September	
19:00 Welcome Reception at Sunley Management Centre	
Thursday 28th September	
08:00 – 15:00	**Registration**
09:00 – 09:20	**Welcome and Introduction** Frank Burdett, Pro Vice Chancellor Research and Business Development, University of Northampton (U.K.)
09:20 – 10:05	**Keynote Lecture 1: Dynamics of Cables: Overhead Lines, Belt Drives and Electrodynamic Tethers** Peter Hagedorn, Technical University of Darmstadt (Germany) **Abstract.** In this presentation, first a number of dynamical problems related to high-voltage overhead transmission lines will be presented and mathematical descriptions will be outlined and discussed. Some of these problems can be well described using a linear theory, others require nonlinear modeling. A modal versus a travelling wave approached will be discussed using several examples. Specific problems to be addressed include wind-excited vibrations due to vortex shedding and galloping, the insulator-chain problem, vibrations of bundled conductors and others. Another interesting class of problems involves the axial motion of a string, belt or web. A linear description here leads to gyroscopic terms in the equations of motion, and care also has to be taken to formulate the boundary and contact conditions in an appropriate manner. Finally, some applications of electrodynamic tethers proposed for certain missions in space will be described, leading to complicated and interesting mathematical problems.
10:05 – 10:25	**Large Tether and Web Structures in Space** M. P. Cartmell and D. J. McKenzie University of Glasgow (U.K.) **Abstract.** Long hanging, oscillating, or rotating tethers for momentum exchange in space are now accepted as viable systems for propulsion. Such systems are capable of exceptionally complex and rich dynamical performance. In addition new research into space webs on which robotic crawlers could perform useful constructional tasks is now of wide interest. This presentation will discuss recent work on motorized momentum exchange tethers and new developments on space webs.

10:25 – 10:45	**Analysis of Elevator Dynamics with Building Block Model Method** D. Fukui, K. Okamoto, H. Kodera and T. Niikawa Mitsubishi Electric Corporation (Japan) **Abstract.** The influence of mischief passenger behaviour on car vibration depends on elevator weight, travel, and roping. Therefore, to correctly grasp these influences, a simulation model must be developed that can evaluate the vertical vibration dynamics of various elevator systems with vibration caused by various sources including passenger behaviour. In this paper, we propose a vertical vibration dynamics simulator for an elevator system expressed with a block model that can be easily changed based on the various system compositions of different elevators. We confirm the validity of a building block model that can evaluate elevator dynamics when mischief occurs by making comparisons by means of an experiment. Using this block model, we investigated the tendency of the vibration level with travel and capacity changes. We confirmed that an emergency stop operation could be prevented through an experiment in which passenger mischief created forced vibration. As a result, we set up a practical detection level and developed a reliable detection system.
10:45 – 11:15	**Coffee**
11:15 – 11:35	**Determination of the Distribution of Specific Pressure between a Wire Rope and a Groove** C. E. Imrak and I. Gerdemeli Istanbul Technical University (Turkey) **Abstract.** Wire rope is used to suspend the car and the counterweight in the elevator installations. The wire ropes of an elevator with a traction drive-hoisting machine are driven by friction on the grooves of the driving sheave. The shape of the groove affects the specific pressure distribution. In this study, the determination of the distribution of the specific pressure along the contact line between the rope and the undercut groove is investigated by means of Airy's stress function method.
11:35 – 11:55	**Finite Element Approach in the Dynamic Analysis of Slender Flexible Bodies with Time-Varying Length Using Multiple Nonlinear Time Scales** Y. Terumichi, S. Takehara, S. Kaczmarczyk and K. Sogabe Sophia University (Japan), University of Tokyo (Japan), University of Northampton (U.K.) **Abstract.** In this study, the modeling and the formulation using the new finite element approach based on the Absolute Nodal Coordinate Formulation (ANCF) to treat flexible elements of time varying length is proposed. This approach involves the application of the method of multiple scales with nonlinear time scales. The paper presents the analysis of a tether system subjected to motion with large rotation, displacement and elastic deformation. The main concepts are introduced and the nonlinear problem is treated by the application of the ANCF. It is shown that in this approach the mass matrix of the system is time invariant despite the fact that the length of the tether is time-varying. An approximate solution is obtained numerically and verified by experimental tests.

11:55 – 12:15	**Lifetime of Suspension Means in Traction Lifts** W. Vogel University of Stuttgart (Germany) **Abstract.** In traction lifts the suspension means are an important and central mechanical element. Steel wire ropes are normally used in traction lifts. New developments have given rise to alternative suspension means such as aramid fibre ropes, flat belts with steel cord reinforcement, etc.. The suspension means have to satisfy the requirements relevant to safety as adequate life time, reliable discard (this means the point at which the suspension mean has to be changed out of the drive) and sufficient and at the same time also limited traction capacity. The following discussion will examine the lifetime of steel wire ropes running over sheaves, the influences specific to lifts on rope lifetime – in particular the reduction of the D/d-ratio and the rope diameter – and the method used to calculate rope lifetime in the application. We will examine all this against the background of the international standardization in lift engineering. The paper continues with a summary of bending fatigue tests with aramid fibre ropes and flat belts with steel wire cords.
12:15 – 12:35	**Static Stress Analysis of Traction Chain Link by Means of Boundary Element Method** C. E Imrak and M. C. Fetvaci Istanbul Technical University (Turkey), Istanbul University (Turkey) **Abstract.** Boundary element methods are well known and frequently used in continuum mechanics problems as an alternative to the finite element method. In this study, roller chains which are used as traction members of conveyors are analyzed. The modelling steps and the application procedures of boundary element method are examined. The mechanical behaviour of a traction chain which is loaded by the maximum load allowed is considered. The application of boundary element methods to traction chain link stress analysis is performed for an illustrative example.
12:35 – 13:35	**Lunch**
13:35 – 14:20	**Keynote Lecture 2: Dynamic Stability of Translating Media with Variable Length and/or Speed** Weidong Zhu, University of Maryland Baltimore County (U.S.A.) **Abstract.** Recent advances in the dynamic stability of variable-length (such as elevator cables and crane and mine hoists) and variable-speed (such as belt and chain drives with speed variation during operation) systems are reviewed. Two types of stability problems are considered: (1) stability of systems during extension and retraction, and (2) stability of systems with periodically varying length and/or speed. New stability characteristics are identified for both systems from the energy viewpoint. The first type of problems with applications to elevator systems is emphasized in this work. In addition to stability analyses, free and forced response solutions using modal, wave, and finite difference methods are derived, and methods to dissipate the vibratory energies of the variable-length systems are addressed. A novel experimental method is developed to validate the uncontrolled and controlled lateral responses of a moving elevator cable with variable length in a high-rise elevator. This includes the design, analysis, and fabrication of a scaled elevator, experimental setup, and development of measurement and parameter estimation techniques. Experimental results show excellent agreement with the theoretical predictions. The application of the new methodology to the design of elevator systems is discussed.

14:20 – 14:40	**Analysis of the Lateral Vibratory Characteristics of a Suspended Rectangular Beam as a Model of a Vibroflot** K. Seto, L. Wang, K. Teramoto and Z. Xu Saga University (Japan), Shenyang Institute of Chemistry Technology (China) **Abstract.** The natural frequencies of a vibratory machine (vibroflot) were analyzed taking into consideration the effect of a rope with which the beam was hung. A vibroflot is a machine used for solidifying ground. Systematic investigations of the effects of the mass of the bottom, the cross sectional area of the beam and the length of the hanging rope were performed. Furthermore, to examine the theoretical treatment, an experiment using an experimental set-up was carried out. The validity of the theoretical treatment was confirmed by the experiment.
14:40 – 15:00	**The Vibration Study of Non-Linear Interactions in a Moving Elevator Car-Suspension Rope System** R. Salamaliki-Simpson, S. Kaczmarczyk, P. Picton and S. Turner University of Northampton (U.K.) **Abstract.** The dynamic response of a moving elevator suspension rope-car is investigated. The elevator model takes into account excitations originating from interaction with the host structure. A multi-degree-of-freedom mathematical model represented by a system of non-linear, non-stationary coupled second order ordinary differential equations which governs the temporal behaviour of the elevator suspension rope-car system is presented. Primary resonances and modal interactions between the lateral and longitudinal oscillations of the rope and the car motions are demonstrated.
15:00 – 15:20	**Pull-in Analysis and Transient Behaviour of a Multilayer Microplate under Actuation of Electrostatic Force** M. T. Ahmadian, M. M. Zand, M. Bonakdar Sharif University of Technology (Iran) **Abstract.** This paper develops dynamics and a pull-in analysis of multi layer microplates using the finite element and finite difference methods. The first-order shear deformation theory is used to model dynamics of the microplate. Using this model, the pull-in analysis of single layer and multi layer microplates are studied. Also, an algorithm is presented to study the transient behaviour of microplates under actuation of nonlinear electrostatic forces and squeeze film damping. These simulations have many applications in designing multi layer microplates.
15:20 – 15:50	**Tea**
15:50 – 16:35	**Keynote Lecture 3: Localisation and Plying in Rod-Like Structures** Gert van der Heijden, University College London (U.K.) **Abstract.** Long slender structures such as textile yarns and ocean cables show localised buckling behaviour under torsional loading. In a 1D elastic theory these localised solutions are described by homoclinic orbits in a dynamical system in which arclength along the structure is the independent variable. Upon continued loading after localisation a snap into self-contact and looping may occur. We discuss the intricate bifurcation behaviour that unfolds after the initial jump and also consider the problem of loop pop-out. We further consider the mechanics of the plied structure that forms and show that the problem is governed by the equations for an elastic rod constrained to lie on a cylinder. This work is relevant for supercoiling DNA molecules and staple fibre yarns. The talk ends with a discussion of the snarling instability observed in whirling transported yarn in manufacturing processes such as false-twisting. A recent asymptotic analysis picks up the instability by means of an internal bending layer.

16:35 – 16:55	**The Thermomechanics of Cosserat Rods** D. Q. Cao, D. Liu, S. Preston, R. W. Tucker Harbin Institute of Technology (China), Lancaster University (U.K.), Portland State University (U.S.A.) **Abstract**: The simple Cosserat description of slender rods is extended to include the coupling to a dynamic temperature field. The Cosserat equations of motion are generalised to include thermomechanical constitutive relations that accommodate thermodynamic constraints imposed by the Clasius-Duheim inequality and the first law of thermodynamics is employed to provide dynamical information on the evolution of the coupled temperature field. Consideration is given to the dissipative aspects of the constitutive laws and the effects of non-linearities on the short-time evolution of the system. Some representative numerical simulations are presented to display the effects of thermal damping on mechanical vibrations.
16:55 – 17:15	**Application of a Newly Designed Cylindrical Super Element to Vibration Analysis of Laminated Hollow Cylinders** M. T. Ahmadian, M. Bonakdar, M. M. Zand Sharif University of Technology (Iran) **Abstract.** A new 16-node cylindrical superelement is presented in this paper and the corresponding stiffness and mass matrices are obtained. It is seen that this superelement can precisely predict the modal behaviour of hollow cylinders. Two examples are presented and the natural frequencies are compared with those obtained from conventional Brick elements. Comparison of the findings reveals CPU time saving and accuracy of the results.
17:15 – 17:35	**Refreshments**
17:35 – 19:00	**Workshop: Elevator Traffic Design and Analysis** Convenor: Rory Smith, ThyssenKrupp Elevator Corporation (U.S.A.) **Scope.** Elevatoring, the technique of applying elevator technology to satisfy the needs of multifloor buildings, is usually studied by lift engineers but is often not well understood. The goal of this workshop is to explain the fundamentals of elevatoring and traffic analysis. The following concepts will be explored: 1. Goal of elevatoring 2. Interval 3. Handling Capacity 4. Round Trip Time 5. Limitations of the Round Trip Time, Interval, Handling Capacity model. 6. Uses of Simulation. 7. Waiting Time 8. Journey Time 9. Time to Destination Simulation will be demonstrated using ELEVATE software.
19:00	**Drinks and Informal Dinner**

Friday 29th September	
08:30 – 12:00	**Registration**
09:00 – 09:45	**Keynote Lecture 4: On the Weakly Nonlinear Dynamics of Axially Moving Belt Systems** Wim T. van Horssen, Delft Institute of Applied Mathematics (The Netherlands) **Abstract.** Since 1970 initial-boundary value problems for weakly nonlinear wave equations have been studied intensively. Several asymptotic approaches (such as multiple time-scales perturbation methods, averaging methods, and so on) have been developed to investigate these types of problems. Since 1990 also initial-boundary value problems for weakly nonlinear beam or plate equations attracted a lot of attention. In this paper a short historical overview will be given and some recent developments will be discussed. In particular the linear and the weakly nonlinear dynamics of a belt system with a relatively low and time-varying velocity will be discussed. For some linear models it turns out that instabilities occur which disappear when nonlinear terms are included in the model. Finally, some results will be presented on related, and ongoing research in this field of nonlinear dynamics in our group at the Delft Institute of Applied Mathematics.
09:45 – 10:05	**Non-Linear Damping in Taut String Cable Theory** Allan Larsen COWI Consulting Engineers (Denmark) **Abstract.** This paper presents a review of taut string theory for prediction of modal damping of bridge stay cables fitted with a viscous damper. Further the paper presents an extension to the well known modal damping vs. damping coefficient diagrams which allows simple evaluation of the influence of non-linear damper characteristics on modal damping.
10:05 – 10:25	**Comparison of Quasi-Steady "Dry-Galloping" Analysis of Inclined Cables Using Two Sets of Wind Tunnel Data** J.A. Symes, J.H.G. Macdonald University of Bristol (U.K.) **Abstract.** Dry-galloping vibrations of cables, due to critical Reynolds number effects, have recently been identified as a potential problem for cables on long span structures such as cable-stayed bridges. An approach to the analysis of the forces causing this behaviour, using quasi-steady theory, has been put forward. This approach has been used to analyse data from two independent sets of wind tunnel tests. A comparison of these results has highlighted the importance of the drag crisis in causing this galloping-type behaviour.
10:25 – 10:55	**Coffee**

10:55 – 11:40	**Keynote Lecture 5: Structural Health Monitoring based on One-time measurements** Helmut Wenzel, Vienna Consulting Engineers (Austria) **Abstract.** The major objective of the Integrated Monitoring and Assessment of Cables (IMAC) project addresses the necessity of extensive technical specification as practical limitation of vibration based Structural Health Monitoring (SHM). The availability of proper measurement technology as well as high-performance analysis software made vibration based SHM an indispensable instrument for infrastructure assessment and maintenance in the sense of permanent and periodic condition monitoring. However, at the same time it was revealed that the actual boundary conditions of a structure and the prevailing environmental influences can be hardly considered in the dynamic analysis of "one-time measurements" on civil structures. The IMAC consortium is aware about the potential of an innovative technique for damage detection and structural condition assessment without knowing detailed specifications and time-dependent factors. Therefore the IMAC project was initiated to identify appropriate approaches and to develop applicable methodologies for the assessment of linear structural elements exclusively based on vibrations. These applications of SHM are limited because in many cases numerical models or former measurements do not provide reliable dynamic parameter due to a lack of essential information about boundary conditions and environmental influences. The IMAC project verifies the feasibility of damage identification based on "one-time measurements" without the need of reference data from numerical models or earlier measurements.
11:40 – 12:00	**Experimental Validation of a Non-Linear Dynamic Cable Model with Axial End Excitation** V. Vidal, C. L. S. Massow, J. H. G. Macdonald, A. J. Crewe, A. R. Champneys University of Bristol (U.K.) **Abstract.** Vibration problems on cable-stayed bridges, when subjected to dynamic excitations such as wind or seismic loads, are well known. In this paper the behaviour of inclined cables when they are excited at the lower end is investigated. The research has involved the use of an analytical model and experimental tests performed on a small scale cable excited at different frequencies, amplitudes and in different directions. The results have shown the complexity of the behaviour and the relevance of non-linear coupling of modes. Finally, future work is discussed.
12:00 – 12:20	**Automatic FE Update after Monitoring of Eigenmodes of Cables** H. Wenzel and A. Mordini VCE Holding GmbH (Austria) **Abstract.** Measurements can provide the necessary information to determine the real behaviour of cables. Three acceleration sensors are applied to the cable in a predetermined distance. The synchronous recording gives information on the mode shapes of the cable and varying conditions. From this information not only the tension force can be extracted but also the bending stiffness and the behaviour of eventual damping devices closed to the anchorages. The free length of vibration is determined as well. The results of the measurements are used to perform an automatic model update. By providing the coordinates of the two anchorage points a FEM model is automatically generated. The update uses the information from the measurements to determine the representative model. The free software OpenSees is used.
12:20 – 12:40	**Experimental Identification of Modal Parameters of a Lift Suspension System** Martyn Maguire, Stefan Kaczmarczyk, Jonathan Adams and Rory Smith University of Northampton (U.K.), ThyssenKrupp Elevator Corporation (U.S.A.) **Abstract.** With the use of modern software packages Operational Modal Analysis provides a convenient and efficient method of modal parameter identification. This technique has proven successful in the field of civil engineering and it is now being investigated for use in the area of lift technology. An aramid suspension system has been subjected to operational modal analysis and modal parameters have been successfully identified. These results have been verified by classical modal analysis.

12:40 – 13:40	**Lunch**
13:40 – 14:25	**Keynote Lecture 6: Achieving Good Lift Ride Quality** Rory Smith, ThyssenKrupp Elevator Corporation (U.S.A.) **Abstract.** Ride quality is usually defined in specifications by levels of horizontal and vertical accelerations felt by the riding passenger while riding in the lift car as well as by sound pressure levels heard by the passenger while in the lift car. The units of measure used for sound and vibration are explained along with the significance of values typically seen in lift specifications. Rails, rope tension, rope resonance, car balance, platform isolation, S curve parameters, motor torque ripple, and guide shoes both active and passive are explored and their influence on ride quality are explained.
14:25 – 15:05	**Invited Lecture: KONE MaxiSpace™ Working Principle and Technical Characteristics** Tuevo Vantanen KONE Elevators Ltd. (Finland) **Abstract.** This paper describes how KONE MaxiSpace™, a new type of counterweight-less traction elevator was developed. The fundamental principles and details of the design, its mechanical efficiency, energy consumption and the issues concerning the riser fuse sizes are presented.
15:05 – 15:35	**Tea**
15.:35 – 16:20	**Guest Lecture: Identifying the Risks in Using Lifts for Evacuation** Derek Smith, Otis Ltd. (U.K.) **Abstract.** This presentation addresses the issue of evacuation of buildings. The risks in using lifts for evacuation are assessed and suitable charts to identify the problems and to develop suitable lift design solutions are provided in the paper. The ultimate goal is to ensure that the final design brings all risks to an acceptable level.
16:20 – 17:00	**Discussion Forum: Evacuation of High-Rise Buildings in Emergencies** **Scope.** The use of vertical transportation systems during building evacuation in the event of fire, earthquake, explosion and other emergency situations has recently attracted the attention of experts working in the areas of vertical transportation, building services and design. In this context, the main objective of the forum will be to discuss the need for creating an international network of experts to support and extend current efforts. It is proposed that a research group comprising academic and industrial experts be established to conduct an in-depth investigation into the problem. It will be essential to consider the lift system in the whole context of the building. The issue of the monitoring of the condition and the dynamic response / vibration of the building structure to detect early signs of emergency events will be addressed in the project. Taking into account the risks involved the research team would then determine the strategy and control algorithms to aid safe egress from building in the event of an emergency.
17:00	**Refreshments and Close of Proceedings**

The Programme is subject to amendment