Vibrations of Flow-coupled Systems

J. Antunes, M. Moreira[1]

Objectives

The general objectives of this project are to develop analytical and numerical methods to solve difficult and important problems in fluid-structure interaction and in flow-induced vibrations, involving strong non-linear effects. The specific objective pursued in 2004 was to model the flow-structure coupled dynamics of multiple immersed spent nuclear fuel racks, which are stored in large pools.

Results

This problem is characterized by coupled vibrations of the racks due to the water enclosing them. When the system is subjected to excitation, during seismic activity, the water is squeezed between adjacent racks, strongly coupling their motions. This problem is typically tackled using FEM programs based on linearized potential flow, involving thousands of degrees of freedom. Our approach simplifies the problem modelling by averaging the flow fields across the fluid gap. Hence, a reduced-order model is obtained in terms of a system of DAEs. On the other hand, this model preserves the nonlinearity of the flow equations, as well as a simplified account of dissipative effects. As shown in the figures below, responses may differ significantly for low-amplitude and high-amplitude excitations, due to nonlinear flow effects. The frequency-spreading of the second response spectrum is evidence of this.

Published, accepted or in press work

1. M. Moreira, J. Antunes. A Nonlinear Model for the Fluid-Coupled Vibrations of Spent Nuclear Racks, *Proceedings of the International Conference on Flow-Induced Vibrations FIV2004, Paris, France, 5-9 July 2004,* ***2****,* 971-987.
2. M. Moreira, J. Antunes. Nonlinear Flow Effects on Immersed Spent Nuclear Racks, *Proceedings of the 7th International Conference on Computational Structures Technology CST2004, Lisbon, Portugal, 7-9 September 2004,* Ed. CD-ROM.
3. M. Moreira, J. Antunes. Fluid Coupled Vibrations of Immersed Spent Nuclear Racks: A Nonlinear Model Accounting for Squeeze-Film and Dissipative Phenomena, *Proceedings of the ASME International Mechanical Engineering Conference IMECE2004/DAS 2004, Anaheim, USA, 15-19 November 2004,* Paper 62353.
4. J. Antunes. Modèle Numérique de l'Écoulement Bidimensionnel dans une Lame Fluide Sous Vibrations : Formulation du Problème, Discrétisation et Exemples, *Internal Report* ITN/ADL-Dec04/2.

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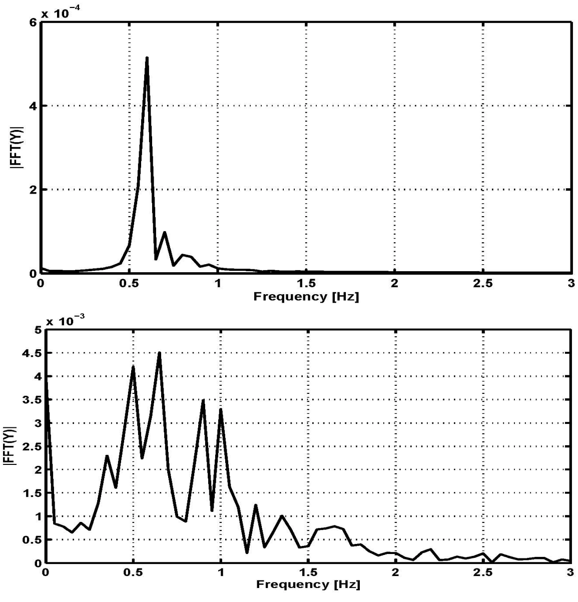

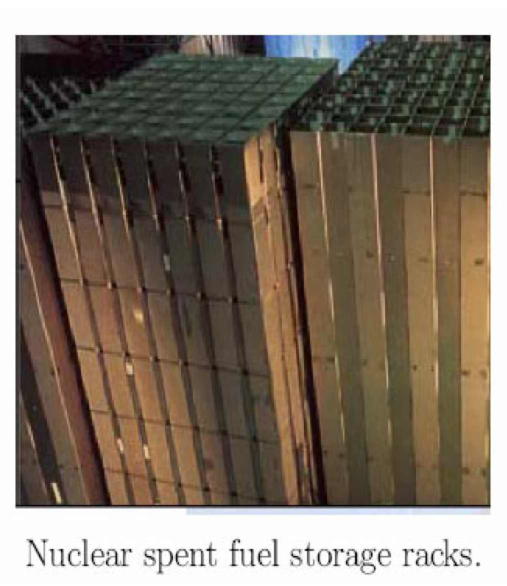

Computations of seismic response spectra of immersed spent nuclear racks subjected to low and high-intensity seismic excitations

Dynamical Modelling of Friction-excited Systems

J. Antunes, O. Inácio[1], M. Wright[2]

Objectives

This project has been, for several years, an international cooperative effort to develop theoretical methods and numerical techniques to deal with strongly non-linear dynamical problems, such as involving impacts and friction phenomena. The main objective for 2004 was development of modeling techniques to account for the influence of complex multi-modal supporting structures, when computing the nonlinear dynamical responses of a given sub-system. These techniques have been applied to a paradigmatic problem in nonlinear physics - the bowed string – but may be adapted to industrial problems of the same nature.

Results

Often, well-defined substructures of interest are dynamically coupled – through their supports – to complex structures for which it is difficult to compute the dynamical properties. Then, their influence must be asserted using experimentally obtained data, in the form of impulse responses or transfer functions. We extended our modal approach for vibratory computations of systems subjected to nonlinear effects to deal with this important aspect. The interaction is modelled in terms of either (a) a convolution integral of the impulse response of the complex structure subjected to the support interaction force, or (b) a modal approach for the structure dynamics, using identified modal properties. The second approach is much faster than the first, but the first one is free from any identification errors. Prospective computations have been performed, based on a bowed string, qualitatively reproducing a well-know interaction problem in string instruments – the so-called wolf note. A significant number of papers emerged from this research.

Published, accepted or in press work

1. O. Inácio, L. Henrique, J. Antunes. The Physics of Tibetan Singin Bowls, *Revista Española de Acústica,* ***35(1,2)*** (2004) 33-39.
2. O. Inácio, J. Antunes, M. Wright. On the Violin Family String/Body Dynamical Coupling, *Proceedings of the Spring Conference of the Institute of Acoustics, Southampton, UK, 29-31 March 2004,* ***26(2)****,* 29-20.
3. O. Inácio, J. Antunes. Dynamical Responses of a Large Tibetan Singing Bowl, *Proceedings of the International Symposium on Musical Acoustics, Nara, Japan, 31 March – 3 April 2004,* Ed. CD-ROM.
4. O. Inácio, J. Antunes, M. Wright. Bowing the Wolf: Simulations and Experiments on a Cello, *Proceedings of the IV Iberoamerican Acoustics Congress, Guimarães, Portugal, 13-17 September 2004*, Ed. CD-ROM.
5. J. Antunes, O. Inácio. Physical Modelling of Tibetan Bowls, Invited Talk, *147th Meeting of the Acoustical Society of America, New York, USA*, 24-28 May 2004.
6. O. Inácio, J. Antunes. Modelling the Nonlinear String/Body Coupled Dynamics of Bowed Musical Instruments, *148th Meeting of the Acoustical Society of America, S. Diego, USA*, 15-19 November 2004.

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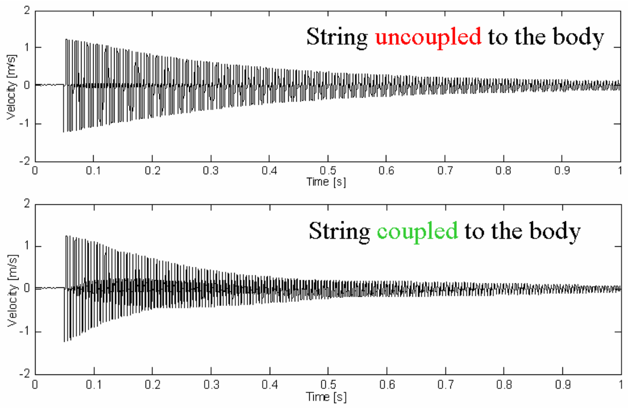

Demonstrative computation of a plucked string, isolated and then coupled to a multi-modal structure

Dynamical Modelling of Geological Inclusions

F. Ornelas[1], R. Taborda[1], J. Antunes

Objectives

The general objective of this project is development of theoretical models to predict the motions of geological inclusions as a function of the shear motions of the enclosing matrix, which can be modeled as a fluid, and their confrontation with experiments (performed at FCL/LATEX). This problem is important for understanding geological structural patterns and their history. During 2004 we addressed two important aspects connected with this problem: (i) the influence of the inclusion shape on the resulting motions, (ii) the resulting matrix flow structure.

Results

A numerical model of the flow subjected to moving boundary conditions, based on the finite-element method as applied to the Stokes formulation, has been developed to deal with both adhering and sliding matrix/inclusion interfaces, for circular and elliptic inclusions. Such model was now extended to deal with inclusions of other shapes, as frequently displayed by nature. Extensive parametric computations were performed using this tool, from which general trends could be inferred. Also, investigation the flow in the matrix surrounding the inclusion, subjected to shear, enabled a better understanding of the influence of the pressure and viscous stress fields on the inclusion kinematics.

From this research two journal papers have been produced emerged, others having been submitted.

Published, accepted or in press work

1. R. Taborda, J. Antunes, F. O. Marques. 2-D Rotation Behaviour of a Rigid Ellipse in Confined Viscous Simple Shear: Numerical Experiments Using FEM, *Tectonophysics* ***379*** (2004) 127-137.
2. F. Ornelas, R. Taborda, S. Bose, J. Antunes. Effects of Confinement on Matrix Flow Around a Rigid Inclusion in Viscous Simple Shear: Insights From Analogue and Numerical Modelling, *Journal of Structural Geology* (in press).

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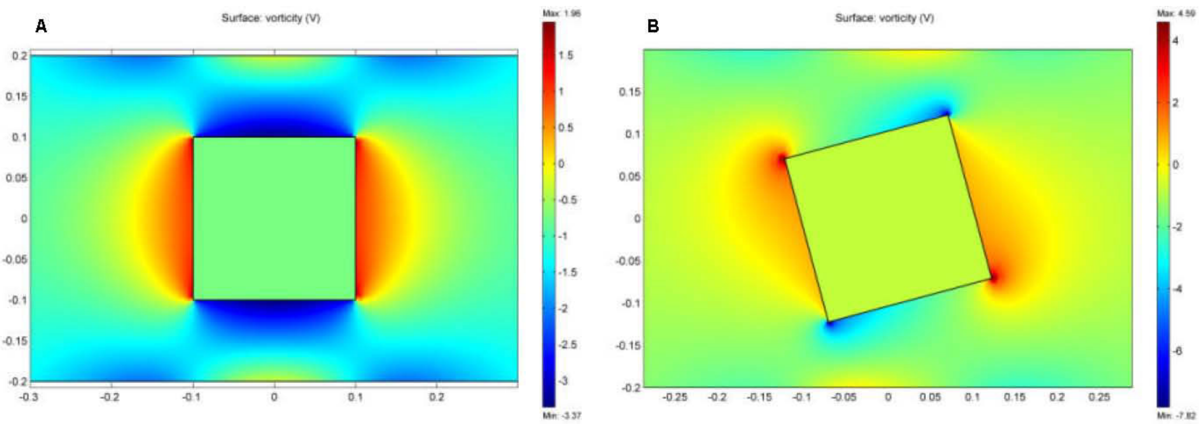

Vorticity of the surrounding matrix under confined shear flow for two different positions of the inclusion

Optimization of Vibratory and Acoustic Systems

J. Antunes, L. Henrique[1], J. S. Carvalho[2], J. Paulino[3], O. Inácio[1]

Objectives

Developing new methods for the optimization of dynamical systems, focusing on the problem of shape optimization, in order to obtain a target-set of resonance frequencies. Following our research of the previous year, our objective for 2004 was to perform experimental validation of the techniques previously developed to model and optimize vibratory and acoustic systems.

Results

We built six different specimens of optimized systems – three vibratory bars and three acoustic resonators – to perform the experimental validation. Shape-optimization results were obtained using simple computational models – Timenshenko beam theory for the bars and uni-dimensional wave-propagation theory for the resonators. Even so, the experimental work performed consistently produced results in close agreement with the predictions for the optimized systems. Further work on more involved 3D finite-element computations of the resonators enabled to better establish the frequency range where simple uni-dimensional acoustic modelling is adequate, as well as contributed to a better understanding of the various aspects connected to the boundary conditions on the open side of the resonator.

This work has been developed in the context of a PhD thesis, which is now concluded.

Published, accepted or in press work

1. L. Henrique. Concepção e Caracterização de Instrumentos Musicais de Lâminas Utilizando Técnicas de Modelação e Optimização, PhD Thesis, Universidade Nova de Lisboa, December 2004.

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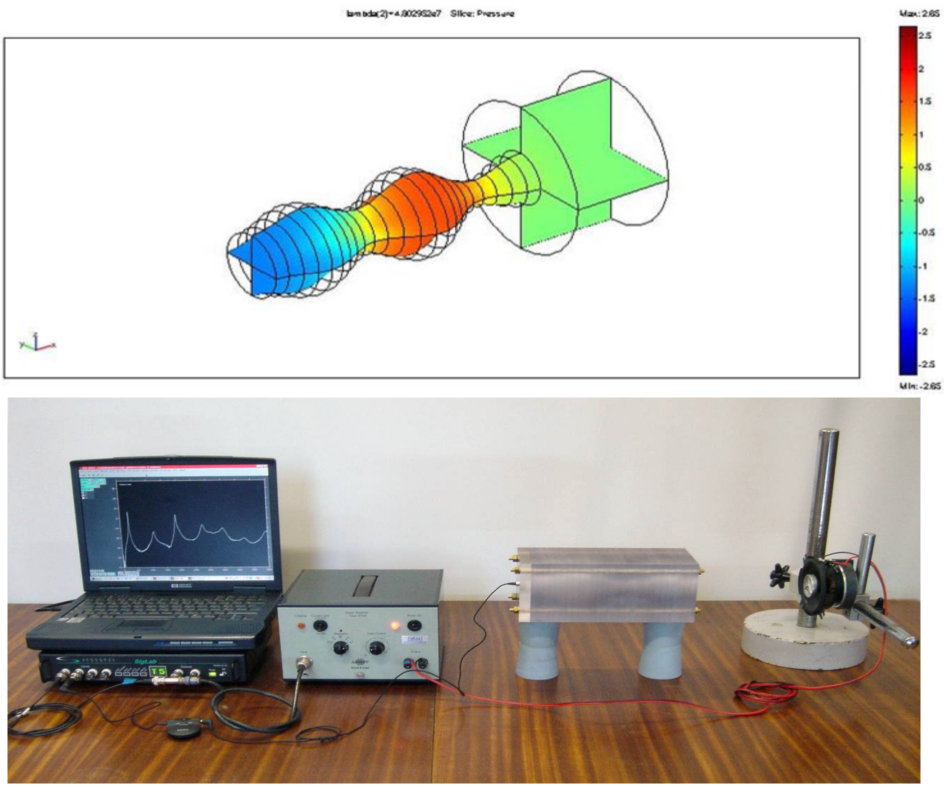

Three-dimensional FEM computations of acoustic modes on optimally-shaped resonators and experimental validation rig