COMPARISON of VIBRATION CONTROL in CIVIL ENGINEERING using PASSIVE & ACTIVE DAMPERS

– COVICOCEPAD –

S3T
A EUROCORES PROGRAMME
EUROPEAN SCIENCE FOUNDATION **CO**LLABORATIVE **RES**EARCH

Smart Structural Systems Technologies (S3T)

Scientific Committee Meeting
ESF Office, Strasbourg, 7-8 September 2006

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Partnership and Leadership of Project (1)

- **Leadership of the Collaborative Research Project (CRP)**

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- **Participating Institutions in the Individual Projects of the CRP**

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Partnership and Leadership of Project (2)

- **Participating Institutions in the Individual Projects of the CRP (continuation)**

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Past Experience and Motivations (1)

- Project PRAXIS 10250/ECM/1998 (duration from 1999-2002) sponsored by FCT (Lisbon) on the Seismic Analysis and Design of Metallic Bottom Supported Steel Tanks using FEM and including Liquid-Structure Interaction (LSI) ; Project Coordinator Leader PL or Principal Investigator PI: RCB at FEUP. **Habilitation Degree: 4 July 2000.**
- Invited on March 2000 to participate in an International Network approved by ESF; effective nomination by ICCTI (Lisbon, Nov 2000) as a national member (1 / 3) of the international network CONVIB.
- International recognition of the successful R&D done at Project PRAXIS-10250, and its applicability for TLD, namely at the 'kick-on' meeting of network CONVIB (Italy, Sept 2001).
- Analytical formulation (2001) about active vibration control (AC) of pipelines (and in general of tube or fuselage structures: airplanes, submarines, rockets and missiles) with piezoceramic 'stacks' of actuators.

Past Experience and Motivations (2)

- Positive interactions with partners at network CONVIB (and later also some from network SAMCO) with successful research under Vibration Control, and consequent thematic motivation on TLD, TMD, TLCD, ATLCD, etc.
- Participation in the 4 years of CONVIB activity, having presented works on TLD and AC (kick-on meeting, Italy 2001) TMD and BI (kick-off meeting, Greece 2005) and published works in: book Intelligent Structures (ed.: Baratta & Corbi), 2 issues of journal EEE (European Earthquake Engng), ECSC (Vienna), CD-ROM of a meeting.
- Unsuccessful submission of 2 R&D project proposals to FCT(July 2002 : for the thematic extension of Praxis-10250 to Lifeline Structures ; July 2004: VICOSEPAD as a national non-approved version of the current international project COVICOCEPAD).
- Actual international CRP – COVICOCEPAD – submitted as a pre-proposal in Nov 2004 (among 55), pre-selected in Jan 2005 for final submission until March 2005 (among 24 remaining), scientifically approved in June 2005 (among other 15). It took FCT 1-year to allocate funds for it, so that officially July 2006 is the project 'kick-on' starting date for Portuguese IPs of the CRP.

Past Experience and Motivations (3)

- With respect to COVICOCEPAD, the following activities have nevertheless been successfully undertaken already in 2006: 2 nominations and tasks as External Examiner of 2 PhD candidates (Feb at Trinity College Dublin , May at the University of Rome) ; approved mini-symposium proposal for ECCOMAS thematic conference COMPDYN-2007 in Greece ; since 'kick-on' date of July 2006, so far 3 communications in Int Conf ICs (2 in last week of July 2006 at the IC Mechanics and Materials to Design M2D-5 , under editors Gomes & Meguid ; 1 next week at the IC CST-2006 under editor Prof. BHV Topping).
- Submission of 2 R&D project proposals to FCT, with deadline 18th Sept 2006, namely on : Assessment of Structural Joints using PsD testing with Substructuring ; Vibration Control of Flexible Structures (Towers and Bridges) using Semi-Active Dampers.

Objectives of the CRP (1)

- Assessment, by distinct partners of this R&D CRP, of the important and actual thematic of Vibration Control in CE Tall and Long Span Structures (tall buildings, bridges, towers, chimneys, or very slender structures with special aesthetics) under dynamic transient or cyclic actions of short or long duration.

Objectives of the CRP (2)

The technical general objctives of the R&D of this CRP are:

- Analytical computational evaluation of the response and behaviour of CE structures using distinct damping techniques for vibration control;
- Compare the results and the behaviour of distinct control algorithms (and dampers) in reference structures or in calibrating structural cases associated with small-scale models;

Objectives of the CRP (3)

- Experimental validation and assessment of real structures or quasi-real large scale structures (European lab infrastructure ECST), to verify the possibility and capacity of some control systems proposed or vibration mitigation;
- Improve Optimize vibration control in CE structures, contributing for the maintenance and upgrading of general infrastructures (of general concern in Lifeline Engineering) and for the mitigation of natural hazards causing vibration responses (EQ, strong winds,...).

Areas of R&D and Key-words of CRP

- **This CRP submitted to the EUROCORES Programme with PESC (Programme in Physical and Engineering Sciences) entitled SMART STRUCTURAL SYSTEMS TECHNOLOGIES (S3T) addresses cumulatively the following areas (and sub-areas) of research within the S3T call: *Modelling of structures* (as dynamic systems, with in-service degradation, with damper devices as integrated structural elements, using modern techniques of shape displacement-velocity-acceleration control and minimisation); *Sensors & Actuators* (by optimisation of emerging technologies for structural applications); *Systems* (by advanced modelling of control systems); *Analysis & Decision Making* (by structural performance evaluation and damage assessment).**
- **Key words** (max. 8): **Vibration Control , Passive - Active Dampers , TMD (tuned mass dampers) , TLD (tuned liquid dampers) , Piezoceramic Actuators , Base-Isolation , Experimental Dynamics.**

Abstract (1)

This project envisions to model passive and semi-active devices (BI, TMD, SATMD,... developing also control algorithms for the optimisation of the global structure (structure + devices); this would also be complemented with experimental tests on shaking tables for algorithm calibration and real-structures estimated performance.

Additionally the proposed-project pretends to develop the mathematical model of TLD and TLCD, for which the damping forces resisting the actions result from: viscous interactions between liquid and rigid container, hydrodynamic head loss from passing orifices, internal viscosity of liquid.

For infinitely rigid container only excited in lateral directions, small displacement theory of the fluid mass and damping sources assumed small and negligible, Sakai (1989) Saoka (1988) introduced a velocity dependent damping coefficient that is the source of non-linearity in the differential equations of motion of the TLCD. To obtain approximate solutions equivalent linearization techniques will be developed and used.

To complement the general studies active control of beam and plates will be analytically assessed, using piezoceramic stacks of actuators and a minimization algorithm of observed vibrations at sensor sections.

Abstract (2)

- Tall or long-span civil engineering (CE) structures should be designed to enable better performance under different actions, particularly dynamic and transient loads. There has been a continuous trend to use damping systems to reduce building (and CE structures) accelerations, velocities and displacements. In CE there are three fundamental control strategies to control the response of a structure (tall building or bridge) fundamentally (but not solely) to wind or earthquakes: passive control, active control, and semi-active control. As technology continues to advance, the need for vibration isolation mitigation and damping becomes increasingly necessary. More reliable devices with a higher frequency bandwidth, smaller size, and lower power requirement are needed. Then semi-active control of vibration is an area of much interest because of its potential to provide these characteristics.

- R&D studies on passive control in CE (through base isolation devices) done in the past by some of the partners of this CRP, will be continued herein through experimentation at LNEC's facilities on behalf of FEUP (PL partner Po-1) and IST (PI partner Po-2) technical interests; additionally, will be applied to real structures by the IST team (partner Po-2).

- Theoretical research presented recently by the PL on active control by ceramic stacks of actuators, will be further developed to beams and plates with the collaboration of partner It-1. Such developments will constitute scientific added value, inducing future sources of R&D namely at FEUP. Additionally experimental analysis of a small-scale 2 DOF shear building equipped with 2 AMD's, will be compared with performance of the structure equipped with proposed TLD's to access relative efficiency of this semi-active damper technique and indicate hints for large scale placing and development of such control devices.

- Some Semi-Active Dampers used as control strategies, will be studied experimentally in this CRP, as well as modelled and partially applied in real CE structures. Emphasis is given to: Dampers Using Smart Fluids; Hydraulic (Fluid) and Viscous Dampers; Tuned Mass Dampers (TMD); Tuned Liquid Damper (TLD and their variants). Collaborative R&D on the development of these strategies and on the structural performance of large experimental structures (located at 2 ECST facilities) equipped with such devices, will involve the 5 partners of this CRP: PL (Po-1), 3 PI's (It-1, Po-2, Po-3) and AP (It-2 JRC).

Partners General Tasks (1)

METHODOLOGY and EXPERIMENTS of individual projects of CRP

- **The theoretical synthesis of most of the state of the art available with respect to base isolation, viscoelastic dampers, TMD, TLD and their extensions TLCD/ ATLCD;**

  (Partners: It-1 UNFII, Po-1 FEUP, Po-2 IST)
- **Use of an experimental pilot unit by PhD students – a small shaking table – as a versatile test equipment for the study of experimental dynamics (vibration control) on structural engineering situations under seismic and transient loads; The use of such shaking table in systematic experiments on an experimental frame with tuned mass dampers (TMD) – and active tuned mass dampers – and a similar frame with tuned liquid dampers (TLD), to draw conclusions on the relative efficiencies of such passive and active control devices;**

  (Partners: Po-1 FEUP)
- **To perform large scale model tests of metallic frames in modular international shaking tables (JRC , LNEC) of the ECST, namely the one´s associated to frames with base isolation devices and TLDs (at LNEC) and frames with viscoelastic dampers (at JRC); data acquisition and structural analysis.**

  (Partners: **It-1 UNFII, It-2 JRC, Po-1 FEUP, Po-2 IST, Po-3 LNEC)**

Partners General Tasks (2)

METHODOLOGY and EXPERIMENTS of individual projects of CRP (cont.)

- **The application of TLD technique to real frame structures in Italy and Portugal (namely at pedestrian bridges in Porto district), to assess the effect of its inclusion in practice and the efficiency of the solutions tested in laboratory at the shaking tables; The analysis of a real 3D base isolated structure in Portugal (Hospital in Lisbon);**
  (Partners: It-1 UNFII, Po-1 FEUP, Po-2 IST)

- **Development of analytical formulations with respect to the passive TLD and active ATLCD techniques, as well as to the active control of beams and plates using piezo-ceramic stacks of actuators, to increase the know-how of the partnership team in this active area of research.**
  (Partners: It-1 UNFII, Po-1 FEUP)

Overall Budget

BUDGET ITEMS	Short Justification of each budget item where appropriate	It-1 AB (UNFii) ITC	It-2 GM (JRC) ELSA Unit	Po-1 RCB (FEUP)	Po-2 LG (IST)	Po-3 RB (LNEC)	Items SUMS
must be consistent with the rules set by the relevant national funding agencies	*Duration where appropriate (in month, including start date)*	*(in Euros)*	*(in Euros)*	*(in Euros)*	*(in Euros)*	*(in Euros)*	*(in Euros)*
Salary costs							
Ph.D. student	Grantees at partners It-1, Po-1 and Po-2	52000	0	58800	29400	0	140200
Post-doc. researcher							
senior researcher							
technician							
student stipend / student assistant							
Equipment per item							
item 1	Small-scale versatile ST2 with incorporated 2-TMD control devices		0	50000			50000
item 2	Computers upgrading		0		3000	3000	6000
item …	Other equipment and Data acquisition material	7000	0		3000	6000	16000
Travel							
conferences, workshops, travel to fieldwork, visits *(including networking within the CRP)*	[7 travels (2+2+3 per year)] * 4 partners = 28 travels	11200	0	11200	11200	11200	44800
Consumables / Running Costs							
including analysis costs	Consumables and Maintenance-Running Costs	3000	0	3000	3000	10500	19500
Publication, Dissemination Costs				4000			4000
Overheads							
if applicable	(allowable % of overheads, as applicable by CNR & FCT)	4240	0	25420	9920	6140	45720
Others							
including access to large infrastructures, shiptime, etc. (please specify)							
	T O T A L S for the CRP partners	77440	0	152420	59520	36840	**326220**

Vibration Regulators (TLD-1)

■新横浜プリンスホテル

1991年竣工

地上42階

延床面積　41,000m²

円筒形超高層ホテル

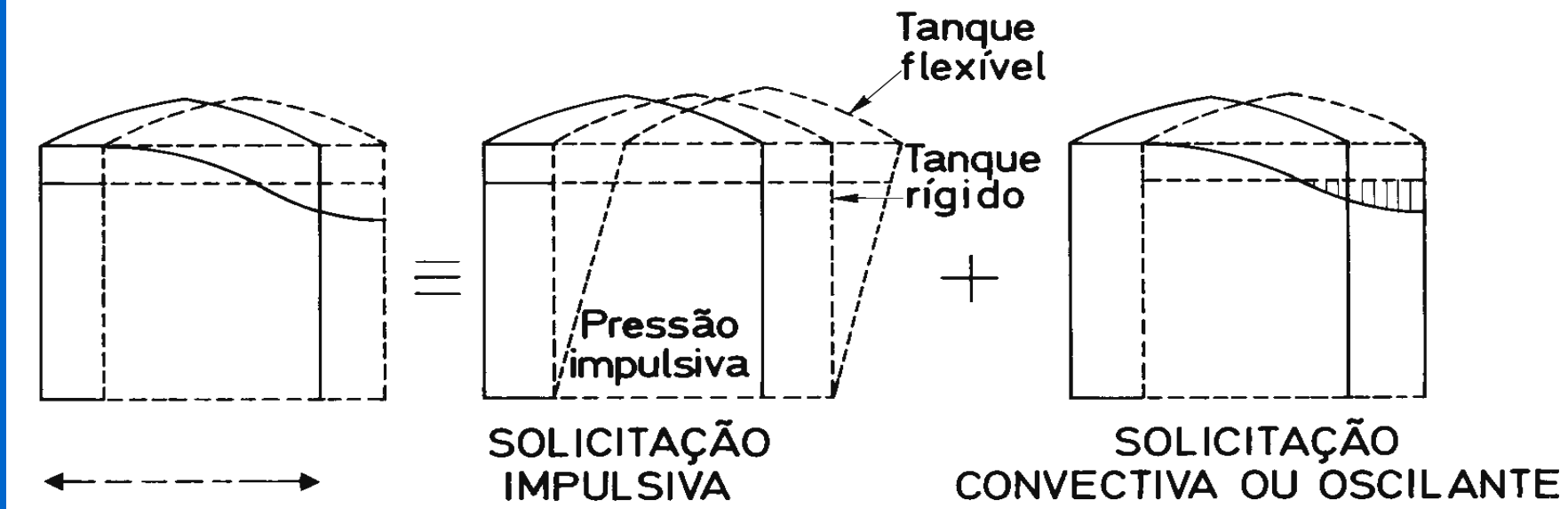
ダブルチューブ構造

SSD(スーパースロッシングダンパー)

屋上の外壁沿いに30台の水槽で81tonの水を設置

Vibration Regulators (TLD-2)

Description of effects and responses (Project PRAXIS 10250/ECM/1998 : Barros, 1999-2002)



- Impulsive response due to the impulsive pressures induced by the inertia forces associated with the impulsive accelerations of tank walls
- Convective response of convective pressures induced by the inertia forces associated with the convective accelerations of the (small) liquid oscillations