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MONITORING THE ONGOING EUROPEAN EFFORT IN STRUCTURAL CONTROL

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SUMMARY

Despite Structural Control does not see its only application in Earthquake Engineering, the latter one represents a field to which special attention is presently devoted by people working in this area- the International Association of Structural Control (IASC) held its second World Conference in Kyoto in july 1998, where the active participation of the President of the International Association for Earthquake Engineering confirmed the reciprocal interest in scientific interaction. The paper emphasizes the effort that European countries, and especially Denmark, Greece, Italy, Portugal and Spain are producing to provide a suitable validation to the application of control theory in structural engineering, paying attention to the existing National- and/or Euro- codes that most times hardly comply with the new approach to safety based on the concept of Intelligent Structures. After mentioning a number of activities that are concerned with the theme of Structural Control in Europe, and also in the Mediterranean area, the trend of potential application of active structural control in the European context is illustrated

INTRODUCTION

This paper moves from a brief overview on the way European structural designers are approaching innovative technologies, despite the constraints of code requirements in a geographical area which only recently was able to conceive common unified rules of design. Of course innovative architectural solutions or increased standards of availability and comfort push toward actively controlled systems. Nevertheless, the associated relatively high costs prevent from a fast spreading of applications, which only address the construction stage or the mitigation of wind induced effects on flexible structures. Examples of bridges and buildings are provided to show the infrastructure innovation in Europe, throughout the nineties.

However an actual promotion of innovative design solutions requires that semiactive, hybrid and active structural control be preliminary conceived and tested in a laboratory environment.

SOME STRUCTURES INCORPORATING THE INNOVATION

Bridges

Despite the design of many bridges belong to the class of the never ended tales, as for the bridge across the Messina Strait, in Italy, the last decade has seen many outstanding bridges studied, designed and built or still in construction. The latter group consists of three main links which are supposed to double the existing capability by completely new parallel connections. All of them are located in Southern Europe countries and cover the areas of Lisbon in Portugal and Istanbul in Turkey, while a third design concerns a bridge in Greece, the Rion-Antirion bridge. All these bridges are located in seismic regions and for all of them the designers planned the adoption of passive devices. Since they are still in construction, it is likely that they will host, at least in the construction stage, some semiactive or active control solutions.

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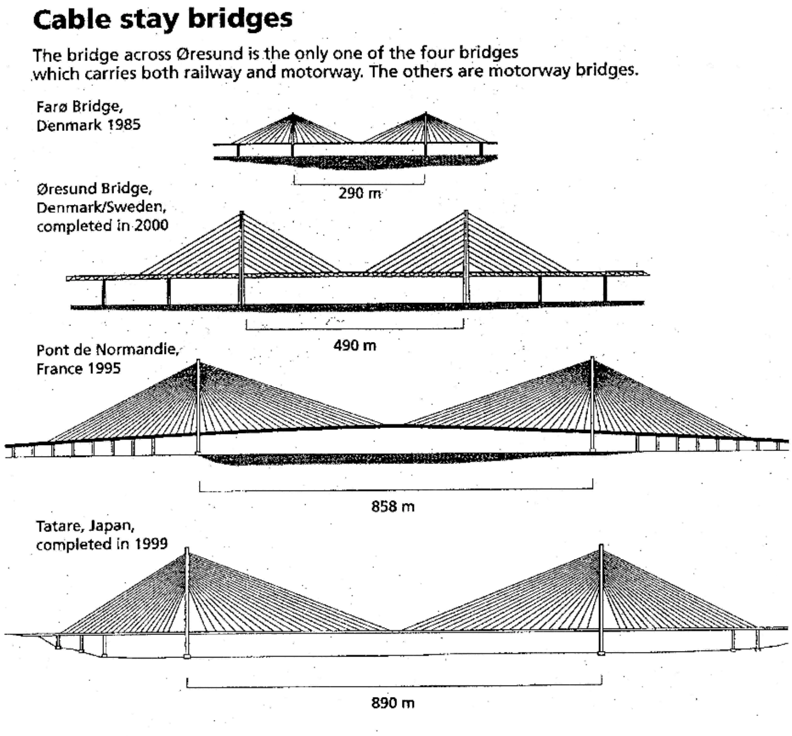

Figure 1 – A comparison of cable-stayed bridges showing the span of the Normandie bridge and the Oresund bridge.

Active control solutions against wind loading were adopted during the construction of the Normandie bridge, in France (Figures 1 and 2), which was recently completed. By contrast, only passive appendages (flaps) were designed for The Great Belt Bridge in Denmark, finished in June 1998 (Figure 3). It is the second-longest suspension bridge in the world. The longest suspension bridge is the Akashy Kaikyo bridge in Japan. No active vibration control was used, but researches are in progress towards the adoption of actively controlled flaps, i.e. towards a semiactive control solution [Hansen, 1998; Hansen and Thoff-Christensen, 1998]. The Oresund bridge is a further component of the link between Denmark and Sweden and is briefly illustrated in Figures 1: it also carries the railway.

Actively controlled solutions are pursued in large scale tests at the Joint Research Center in Ispra as illustrated in Figure 4. The reader is referred to the recent report by Magonette et al. (1999) on this topic for further details.

Figure 2 – The Normandie bridge in France, actively controlled during the construction

Figure 3 – The Great Belt suspended bridge, in Denmark, passively controlled by flaps

Figure 4 – The large scale test on a suspended bridge in progress at the Joint Research Center in Ispra

Buildings

Moving from bridges to buildings, two are the towers which are worth being mentioned. The tower in Frankfurt, Germany (Figure 5a), was simply equipped by an active mass driver (AMD) on the top to mitigate the wind induced vibration. The same purpose is pursued in London, UK (Figure 5b), where the top equipment of a skyscraper under design is just a commercial AMD produced in Japan.

Other classes of structures

Investments, but no realisation till now, are characterising two special classes of structural systems: offshore platforms [Nielsen et al. 1999] and monumental buildings [Anton and Casciati, 1998; Casciati, Maceri et al. 1998; Baratta, 1999a]. The advantages they offer are mainly two: (i) their intrinsic value is able to justify the high costs the innovation requires; (i) they are ruled by specific codes and the resulting design may disagree with the present Eurocodes.

As an example of the possibility to control the dynamic response in some common masonry structural pattern, consider a circular portal-arch, subjected to a seismic ground shake. The arch model, interpreted by a rigid-failure scheme in masonry material, is supposed to be equipped with a tie-rod, whose length is ruled by a control algorithm.

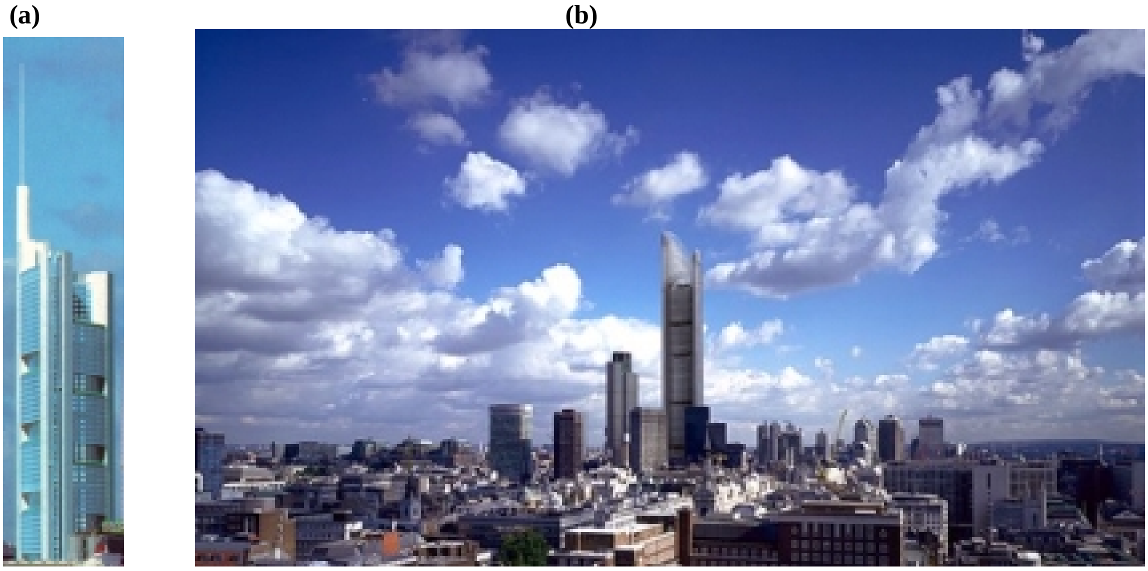

Figure 5: a) The Frankfurt tower actively controlled by an active mass driver against wind loading. (Commerzbank: 260 m tall; 62 stores)

b) A sketch of the London tower to be equipped by an active mass driver. (London Millennium Tower

This model is considered to constitute an intermediate condition between two single-mode cases: i) the arch without tie (Figure 6a); ii) the arch with non-stretch tie (Figure 6b). Bi-modal behaviour [Binetti et al., 1997] is obtained by linear combination of the two single modes through time-varying coefficients measuring the entity of opening of the hinges, depending on the dynamic equilibrium conditions.

The mechanisms to be combined must be chosen in way that, depending on the sign of the combination coefficients, the deformation results in *opening* of every hinge, in the respect of their *unilateral* character.

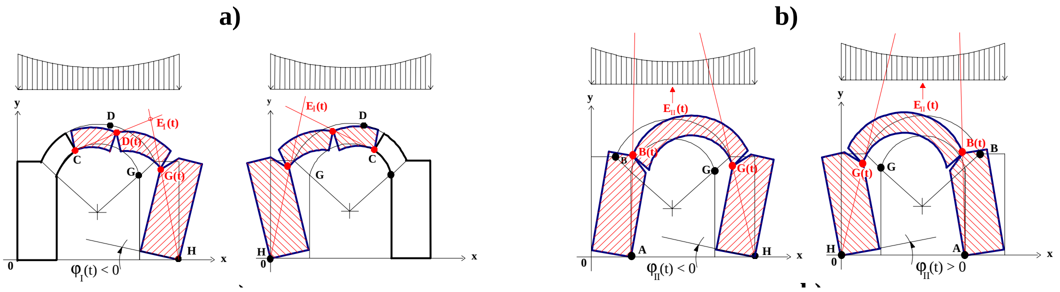

Figure 6: The two arch dynamic-modes: a) the first mode (no tie); b) the second mode (unextensible tie)

The result is that during the motion, the structural system is supposed to be subjected to the activation of two subsequent mechanisms (clockwise and anti-clockwise). The final two-mode behavior, referred to the arch equipped with an extensible tie, is shown in Figure 7.

After inserting the controllable tie rod, an algorithm must be studied to control the length of the tie in way that

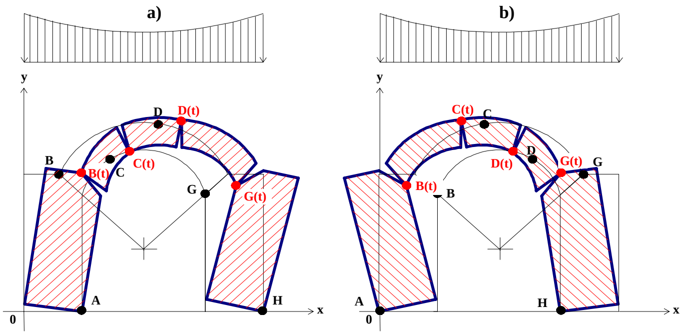

Figure 7: The bimodal combined oscillation mode

the structural response is attenuated.

Assuming the control law in the linear form the objective of the control is to keep as small as possible the oscillation amplitude without requiring too large elongation of the tie. The problem can be solved by a *norm* approach [see Baratta et al. 1998a]. The results prove that the seismic capacity of the portal can be significantly improved.

TESTING THE INNOVATION AND INNOVATION IN TESTING

Hybrid base-isolation system

An order from a museum to a producer of base isolation devices made available low damping elastomeric bearings in a size consistent with the shaking table facilities available at the Department of Structural Mechanics of the University of Pavia in Italy [Casciati et al. 1998; Petrone 1998]. The way the bearing was installed is made clear in Figure 8.

The mass the shaking table can bear is 400 kg. This means that one base isolator is enough as vertical support, but more isolators would provide an excessive horizontal stiffness. The two further supports were realised by a steel-teflon contact. It showed good sliding capabilities under a mass of 100 kg, while for the mass of 400 kg a significant friction effect was emphasised [D'Andrea, 1999].

The laboratory tests were able to identify the device behaviour by collecting absolute inertial force /relative displacement couples and deriving the constitutive law by a genetic algorithm. The fatigue failure of one specimen was also achieved during the experimental activity.

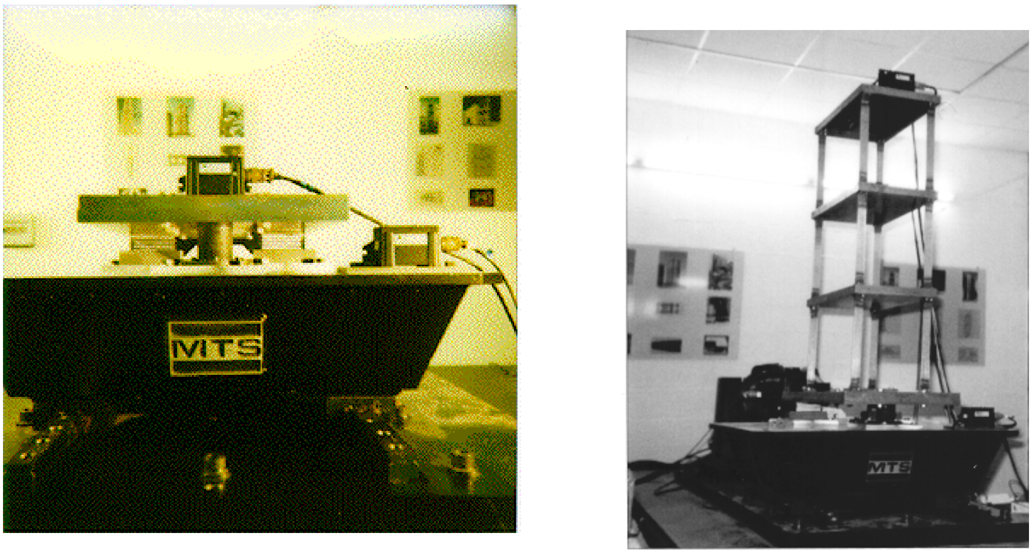

Figure 8 – Base isolator as passive control device and the base-isolated three-story building

Semi active control system

A special class of passive devices, which offers affordable costs and good efficiency, is the one of the so-called tuned liquid columns (TLC). Columns is appropriate because most of the existing applications were realised by cylinders (Figure 9a). Their inconvenience is the narrow band of frequencies of effectiveness. A first idea was to move from cylindrical tanks to conic tanks (Figure 9b), with two main advantages: a lower mass of liquid can be used because of the wider area where the water can spread around and, of consequence, the possibility of moving from one frequency to another by simply adding a thin layer of water [Tagliente, 1999]. As Figure 10, a) and b), show, the conic tank develops its action over a broader range of frequencies, thus reducing the effects of inadequate tuning.

Nevertheless, the efficiency is largely increased only if semiactive devices are added. They are made of bodies which are introduced in the water on command so that the disorder of fluid motion increases the amount of energy dissipated. Once again the whole device requires sensors and a control law built in a standalone board.

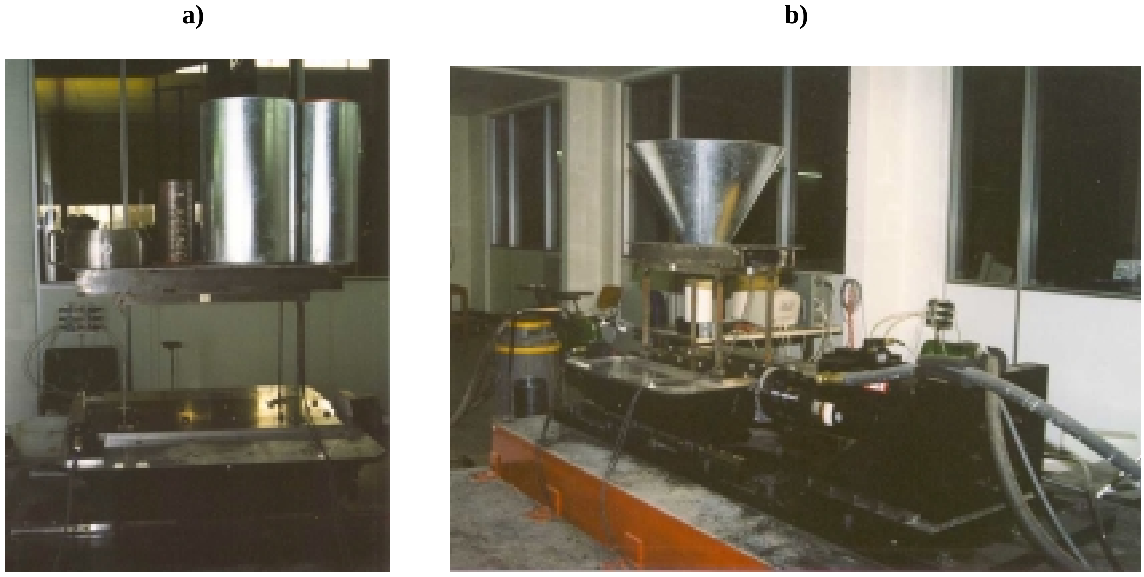

**Figure 9: a) Cylinders to be used as tuned liquid dampers;
b) Conical tanks to be used as tuned liquid dampers.**

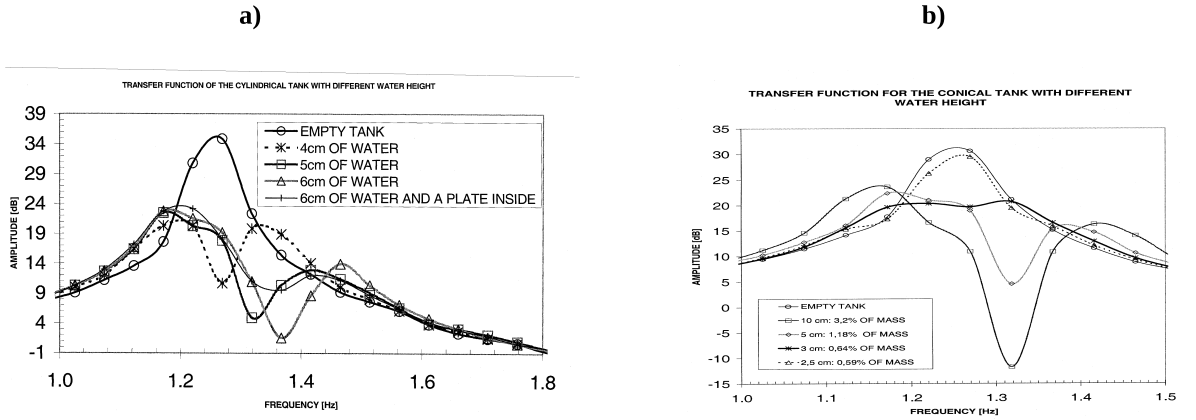

**Figure 10: a) Comparison between the transfer functions of the system in Figure 9a)
with different heights of water in the tank.
The lower case refers to a semiactive scheme.
b) Comparison between the transfer functions of the system in Figure 9b) with different heights of water in the cylindrical tanks.**

Active air jet control system

Following an idea coming from aerospace engineering and already investigated in a structural context by Caughey and Masri, [Beckley et al., 1982], the adoption of air-jet actuators was first investigated in the laboratory of the University of Pavia with reference to a cantilever beam (Figure 11a) [Brambilla et al., 1998; Brambilla, 1999].

The main advantage of this active system is that the energy that will be required to activate the actuators during the external excitation is stored in the form of compressed air. This means that one has not to wonder of the actual availability of an external power source during a seismic event. The frame of Figure 11b) was built and the actuator consists of three electrovalves, each with its own nozzle, on the two directions. Different policies of opening/closure were adopted together with different control laws. Figure 11c) illustrates the ability of the system to reduce vibrations [Fumagalli, 1999].

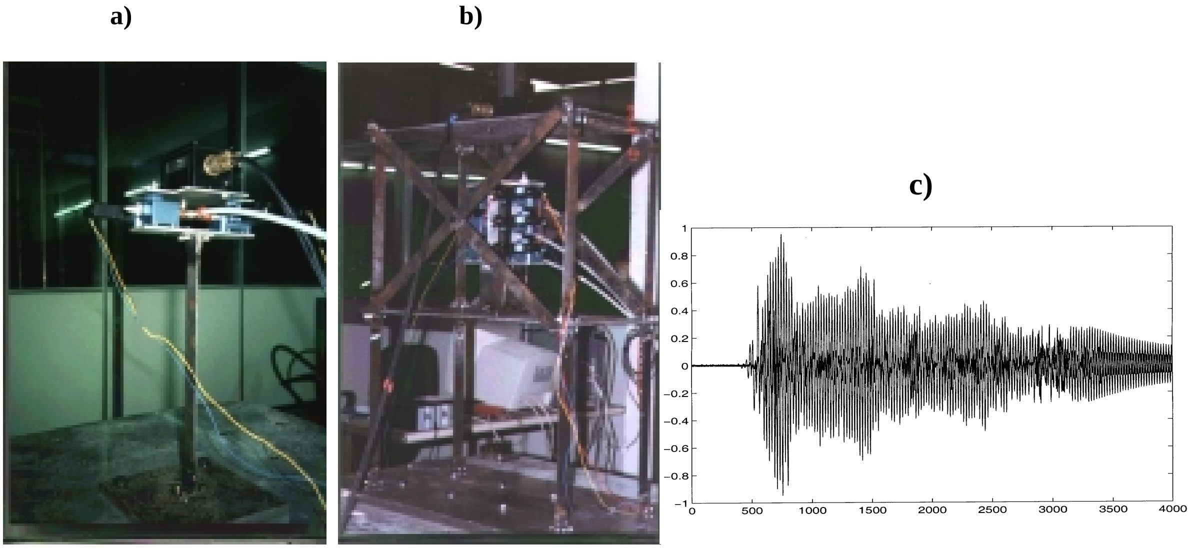

Figure 11: a) Cantilever beam used in the laboratory tests. On the top of the beam an accelerometer acquires the absolute acceleration.

b) Frame used in the laboratory tests. The controller device composed by the three electrovalves applies its force in correspondence to the barycentre of the structure.

c) Comparison between controlled (dark line) and uncontrolled case using the acceleration of El Centro earthquake as excitation.

Control technology in small-scale dynamic testing

An area where the experience gained by active control technology may help in assessing seismic behaviour of masonry buildings is the design of experiments on small scale models of actual buildings to be tested on a shaking table (Figure 12).

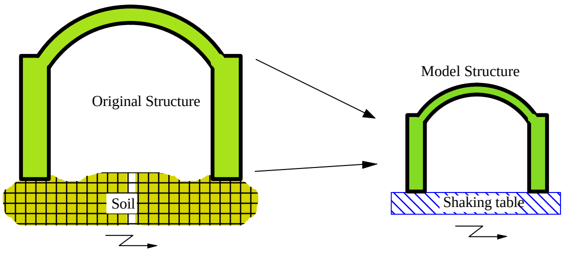

Figure 12: The original building under an earthquake and its scaled model on the shaking table

It can be proved in fact [Baratta et al., 1996; Baratta, 1999b] that if one aims at predicting the seismic response of the original full-scale body, it is possible to compensate the most significant discrepancies between the model response and the original's one, by suitably modifying *on-line* the initially prescribed movement of the shaking table; in other words by *actively controlling* the movement of the table by a suitable algorithm in function of the response parameters of the model while being tested.

CONCLUSIONS

Active and semiactive control is becoming one of the solution the designer considers in the design process of a new building or in conceiving solutions for the rehabilitation of an existing infrastructural component. Applications in the construction stage or to mitigate the vibration under wind loading are becoming more and more frequent. Earthquake engineering applications are still lacking in Europe, mainly due to the strict constraints the structural codes offer and the impossibility of implementing a standard linear control. Nonlinear control is the case for special hybrid, semiactive and active situations. Research efforts to improve the theoretical insight and to extend the experimental validation for application of control technology in civil and aseismic engineering are under current development.

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