THE JRC-ELSA CONTRIBUTION TO THE STRUCTURAL ASSESSMENT, MONITORING AND CONTROL OF THE EUROPEAN BUILT ENVIRONMENT

Vito Renda and Georges Magonette
EC/JRC/ELSA, Via E. Fermi, 21020 Ispra (VA), Italy
Fax: +39 (0332) 785645; E- mail: vito.renda@jrc.it

Abstract

The European Laboratory for Structural Assessment (ELSA) is engaged since many years in research toward supporting the development and validation of techniques and devices for the control of vibration of structures. The experimental campaign, originally focused on passive systems for the reduction of the consequences of strong earthquakes (base isolation, energy dissipation systems), evolved to include also control of vibration due to normal operational conditions. This leaded to investigate the effectiveness of active and semi-active control systems for cable stayed bridges and other applications. The next step was to investigate the effectiveness of non-destructive innovative diagnostic systems to assess the damage and the residual lifetime of the bridge cables. A new project proposal (E-MOI, European Built Environment Assessment and Health Monitoring Initiative) is under preparation and focused on structural health monitoring. It will be finalised end 2003 and submitted to EC-DG-Research for funding. If the project will be selected and funded, it should start mid 2004 for duration of 4 years. The proposal, consisting of several subprojects, includes also Partners from overseas stimulating the International collaboration mainly in full/large scale laboratory and demonstration tests.

INTRODUCTION

The Joint Research Centre (JRC) is a General Directorate of the European Commission (EC). JRC is engaged since many years in investigation on techniques for structural control. In particular the European Laboratory for Structural Assessment (ELSA), at the JRC site of Ispra (Varese, Italy), contributed in supporting innovation in the field of control of vibration. The active and semi-active control techniques are investigated through the participation to shared cost actions of the EC DG-Research with other Partners from different countries of the European Union. In general the contribution of ELSA is mainly in the field of the demonstration of effectiveness and validation of the innovation technologies due to its unique characteristics allowing testing on full/large-scale model of structures (Renda *et al.* 1999).

As regards Active Control, a European Consortium executed the EC project ACE (Active control in Civil Engineering). JRC contributed to the validation of the active control system performing a testing campaign on a large-scale mock-up of cable-stayed bridge. The aim was to strongly damp the cable and

deck vibrations by using active hydraulic actuators in series with two cables (Magonette et al., 1999 and 2001). The results showed that the system induces very high damping in the structure (until about 13%) and contributes to a very strong reduction of the bridge-deck vibration (from about 40 cm to 2-3 cm). Other technologies, based on magneto-strictive materials, have been proven to be effective but not suitable for bridges due to the reduced force-displacement performance; these actuators are of interest for higher frequencies and reduced force-displacement requirements.

The success obtained with the project ACE, induced a partially new Consortium to investigate the effectiveness of semi-active control (needing lower energy demand) obtained with hydraulic actuators as well as actuators based on magneto-rehologic fluids.

The EC project CASCO (Consistent semi-Active Structural COntrol) investigated the potentiality and limits of this technology. Its application, for damping vibrations and consequent acoustic discomfort produced by trains running in galleries, was proved and validated at the ELSA laboratory.

After CASCO, JRC is moving in the direction of structural health monitoring in the framework of the EC DG-Research project IMAC (Integrated Monitoring and Assessment of Cables). Large-scale cables loaded by both ambient and forced induced vibration, will be monitored with non-destructive innovative monitoring-assessment systems. The damage and life prediction obtained from the systems will be compared with observation on the cable with destructive tests at the end of the experimental campaign.

The most meaningful and publishable results obtained from the above-mentioned projects will be diffused through the Thematic Network SAMCO (Structural Assessment, Monitoring and COntrol) and its Database installed and managed at JRC-Ispra. All these activities in structural control and health monitoring brought JRC to become core partner in the Integrated Project proposal E-MOI (European Built Environment Assessment and Health Monitoring Initiative), which will be submitted for funding to DG-Research in FP6 research actions.

SUMMARY OF THE PROJECT ACE

The main objective of the project ACE (Active control in Civil Engineering) was to develop and validate a technology to upgrade the damping of long bridges and consequently to mitigate the vibrations induced in the stay cables and in the deck.

The theoretical basis of an innovative control technique has been established at Brussels University and an exhaustive experimental analysis has been carried out at ELSA to validate the performance of this innovative control technique. A large-scale bridge mock-up (30 m long) has been constructed in the laboratory. A typical cable stayed bridge is shown in Figure 1 (Pont de Normandie) and a large-scale mock-up (not related to Pont de Normandie) built at JRC-Ispra is shown in Figure 2.

Taking advantage of the unique capabilities of the laboratory in large-scale structure dynamic testing, the mock-up was subjected to very severe forcing inputs to verify the damping capability of the system. The structural control scheme consists of a number of important components such as sensors, controllers, actuators, and power generators that must be part of an integrated system. Moreover, a number of implementation aspects must be addressed such as intermittent and fail-safe operations, integrated safety, reliability and maintenance.

The results of dynamic vibration are shown in Figure 3 (case without control) and in Figure 4 (case with active control). The effectiveness of the system is evident.

Figure 1: Typical cable stayed bridge

Figure 2: Cable stayed bridge model at ELSA

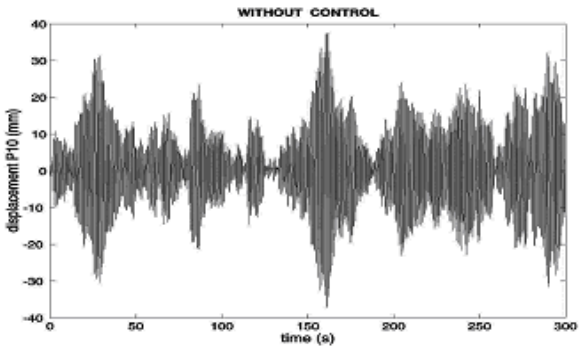

Figure 3: Bridge deck displacements without active control

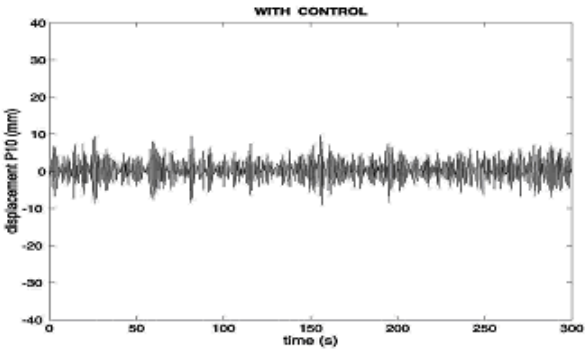

Figure 4: Bridge deck displacements with active control

SUMMARY OF THE CASCO PROJECT CASCO

CASCO (consistent semi-active structural control) is executed by an international consortium. It is related to the use of semi-active devices to damp vibrations in railway tunnels generated by trains. The concern for the environmental and the quality of life of citizen forces policy makers to transfer the transportation of goods from the traditional heavy trucks to railways. However railway companies are subjected to strong resistance and objections to build new railway lines until the problem of vibration exposure to citizen is solved.

The effects of noise and vibration on European citizen were proven to have a negative impact on the quality and comfort of life, performance levels, health and working environment. Among the most familiar ones are motion thickness, deprivation of sleep, physiological effects such as fatigue and psychological effects such as irritability. Reducing or eliminating noise and vibration to the human body will thus have a positive impact on health, safety and well being of citizen.

Innovative methods are required to notably reduce noise and vibration, at the same time minimising energy and material use. One of the goals in this project is to use advanced materials (rheological fluids) to increase the effectiveness of damping elements, while at the same time minimise their geometric dimensions. Rheological actuators must be installed at critical locations throughout structures and underneath railway tracks to eliminate vibration. Thus, kinetic energy is dissipated locally before it is transferred to other components or to the ground. As a consequence, the size of individual viscous

dampers is reduced, allowing a more effective use of materials and minimisation of resource consumption.

Simple possible active and semi-active control schemes are shown in Figure 5 and in Figure 6.

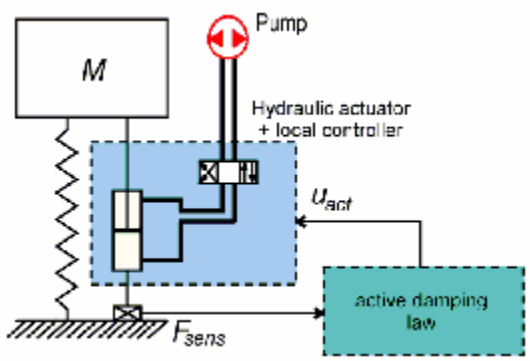

Figure 5: Active control scheme

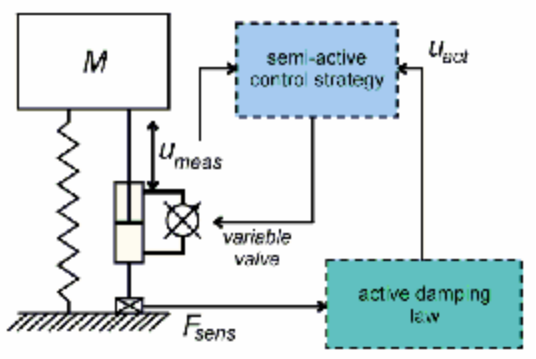

Figure 6: Semi-active control scheme

A test campaign performed at the ELSA laboratory allowed verifying the effectiveness of the semi-active systems for damping of vibrations. Tests were performed initially on the same mock-up used for ACE project with semi-active hydraulic actuators. The hydraulic actuator used for damping the vibration of the cable-stayed mock-up gave, for bandwidth noise, the results of Figure 7 and Figure 8.

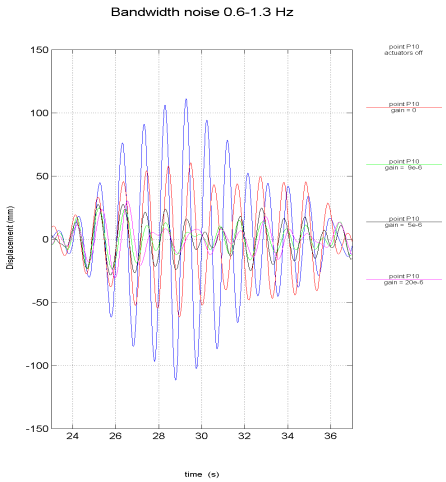

Figure 7: Bandwidth noise without and with control (moderate and high gain)

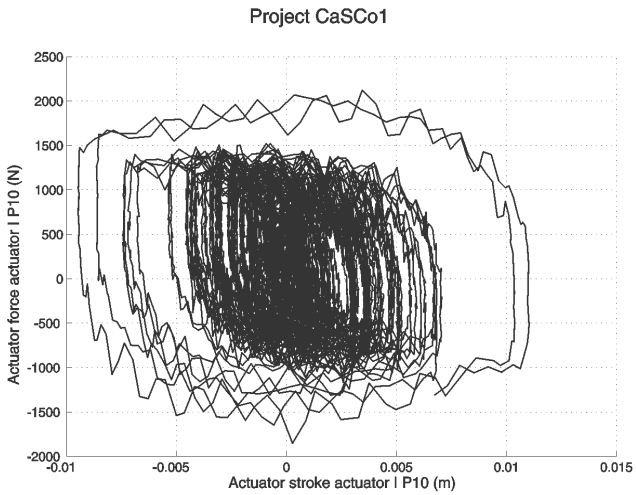

Figure 8: Energy dissipation (actuator hysteretic loop)

The results obtained and the comparison with ACE project shoved that semi-active systems are promising for possible application in bridges, which are structures of strategic value.

The test campaign underway at ELSA foresees the use of two other mock-ups. The first, shown in Figure 9, consists of a concrete slab simulating the bearing structure of the railway in a tunnel. The second, shown in Figure 10, is part of an old Austrian railway bridge. The concrete slab mock-up was used also to perform experimental tests on various types of dampers and mixed spring/dampers devices based on passive energy dissipation, some of them having possibility to adjust the stiffness and the damping characteristics. This testing campaign is considered of relevant interest by the industrial

partners of the project because of the acceptability of passive solutions by the railway owners.

Figure 9: Concrete slab mock-up

Figure 10: Part of old Austrian railway bridge

As regards the rheologic actuators, some of them has been delivered and will be characterized at ELSA. The test campaign will provide some preliminary information on the capability of this type of device for damping structural vibrations. In fact for reasons of costs the industrial partner engaged in designing and manufacturing such devices will provide only a limited number of them for testing at the ELSA laboratory.

OVERVIEW OF THE PROJECT IMAC

IMAC (Integrated Monitoring and Assessment of Cables) is a European project having as main objective the development and validation on innovative non-destructive diagnostic systems for bridge cables. The project, which is now underway, is well integrated with ACE and CASCO and is an important step toward structural health monitoring.
The new diagnostic systems will be tested and validated mainly in the new ELSA testing facility designed and constructed to this end. The facility is essentially composed by the Reaction Wall and a new testing platform about 40 m long embedded in the soil as shown in Figure 11; a view of the Platform under construction at ELSA is showed in Figure 12.

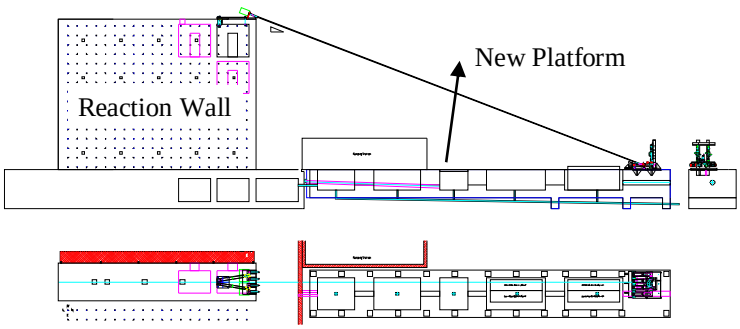

Figure 11: Reaction Wall and Platform general view
(The facility allow testing cables about 40 m long)

Figure 12: Platform under construction at ELSA

Other experimental activities will be performed with a steel frame allowing testing of cables 16 m long. The cable will be maintained in tension and put at different angles compared with the soil as shown in Figure 13; the steel frame is shown in Figure 14. This test campaign is planed to investigate the effect of the dead load and consequent deflection on the cable vibration.

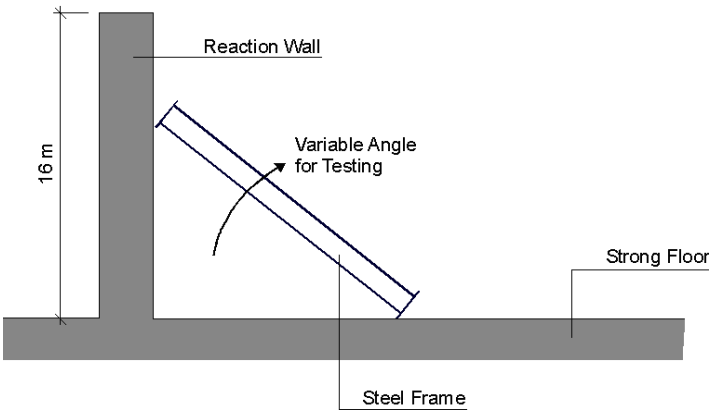

Figure 13: Steel frame in angular position

Figure 14: View of the steel frame

OVERVIEW OF THE SAMCO NETWORK

SAMCO is a Thematic Network funded by DG-Research under the Programme GROWTH with the main aim collect, organize and make available for all interested people the deliverables (knowledge, results and reports). It is organized in various areas including an End Users Forum, Scientific Thematic Groups and a Certification Consulting Point. It will include all deliverables available from the partners and all projects in which they contributed; also deliverables from other consortia will be included when available.

The main objectives of SAMCO

- Ø To create a centre of knowledge and reference at JRC in Ispra, Italy.
- Ø To carry out recommendations for code for monitoring, assessment and control of structures.
- Ø To provide information about the experimental testing capabilities and allow a big audience to see the tests, use the capacities and learn from it.
- Ø To address the specific situation of the transportation sector, particular the railways, where huge investments are foreseen in Europe.
- Ø To organise summer academies for improvement of the education situation.
- Ø To create a certification agency to help to overcome duplication and costly parallel development.
- Ø To compare the European knowledge, standards, technologies and testing techniques with non-European countries.

SAMCO consists of twenty partners and more than hundred participants both from Europe and non-European countries. The Database at JRC-Ispra will be the focal point of the knowledge junction and transfer through the Network and the Participants. The Database will be accessible via Internet and the consultation will available for all the participants. The most relevant data and reports will be organized following the indication provided by the End Users Forum to assure the best outcome as regards the usefulness of the information.

THE INTERNATIONAL SAMCO PROPOSAL

Closely link to the SAMCO Thematic Network, a new proposal (selection underway) has been submitted to EC DG-Research aiming to give to SAMCO an International dimension. In fact in the field of Structural Assessment, Monitoring and Control there have been several European activities focusing on basic research (in FP4 and FP5) as well as on industrial research aiming at the market introduction and practical application of novel technologies. Also intensive networking activities in the frame of the EU thematic networks have been carried out (SAMCO, E-Core, etc.), mainly targeting at a European exchange and transfer of knowledge. Nevertheless a holistic initiative to strengthen the European Research Area (ERA) is yet lacking in the field of structural assessment, monitoring and control. This project is an attempt to contribute actively to the exchange of knowledge and dissemination of the results from European networks, in particular of the SAMCO network, to third country organizations, in order to identify possible lacks and deficiencies in European R&D and to identify future focal points for the European research and development. In most R&D fields, collaboration between European and non-EU research teams is essential to ensure exploitation of research results at al global scale and to build interoperable technology solutions.

SUMMARY OF THE E-MOI PROPOSAL

The integrated project EMOI is designed to generate the knowledge required increasing Europe's competitiveness in the subject of health monitoring and structural assessment. It is an objective driven research initiative, where the primary deliverable is new knowledge generated through targeted basic research, and developed till a realistic exploitation level. It contains long term or "risky" research objectives down to societal needs driven methodology development.
A structuring effect of European research is achieved by co-ordinating all relevant resources and parties into a single initiative. Isolated health monitoring systems will develop into a more general use. More structures will have more standard monitoring systems and operate on a common data assessment platform.

A major vision in health monitoring is:

- The synthesis of different methodologies from different countries and engineering areas;
- Synergy effects and efficiency progress of health monitoring in plant emission control;
- Improved safety assessment and lifetime prediction by decision support systems;
- Increasing of EU competitive capacity in plant engineering;
- Increase of safety availability and economy of European engineering structures.

Health monitoring should be foreseen already at the design stage and shall be embedded during construction. Smart instrumentation and expert systems for structural assessment that require minimal human intervention are desired. This technology shall be employed crossover all industries.

The sub-project "laboratory tests and demonstration"

The main objectives of the sub-project Laboratory Tests and Demonstration are:

- Networking of Laboratories and Testing Facilities offering to the sub-projects a service of laboratory testing capability for the validation of diagnostic systems, technologies and tools for structural assessment;
- Manage and organize demonstration tests to prove to end-users the effectiveness of monitoring

and structural control and/or protection systems for application in real cases;

- Ø Contribute to training of young scientists in experimental techniques acting as hosting laboratories;
- Ø Contribute to NAS integration both by hosting in EU laboratories Visiting Scientists and including NAS Laboratories in the Network.

The research approach

The research approach will consist in offering the following services:

- Ø Allow performing measurements before and after testing of full/large scale structures in order to assess the effect of the damage on the structure and calibrate diagnostic systems (this action takes advantage from the large number of structures tested, for various projects, in the facilities of the Network);
- Ø Perform laboratory tests on structures including specifically designed for the project and including innovative instrumentation and diagnostic systems in order to assess their performance and validate them by comparison with traditional systems and/or inspection of the structure;
- Ø Act as Network of hosting Institutions for training of EU and NAS young scientists and visiting scientists including them in the Teams performing experimental activities underway during their period of permanence (this will allow also training in overseas hosting laboratories included in the international collaboration);
- Ø Contribute with the appropriate experimental background to design and manage demonstration tests on large installations (or real structures) to enhance the acceptance of the technologies and systems to the End-Users owners of relevant structures and transport infrastructures.

The International Collaboration

Since the preliminary preparation of the proposal, the Consortium accepted the JRC suggestion to include Partners from overseas setting-up International Collaboration in structural health monitoring. Being E-MOI a proposal to be submitted for funding to the European Commission DG-Research, the International Partners cannot be funded by the project. It is necessary that the project content be of interest to the International Partners to reach agreement on the collaboration content, which could include tests performed in various laboratories and coordinated in a unique tests campaign.

REFERENCES

Renda, V.; Taucer, F.; Bono, F.; Magonette, G.; Molina, J.; Verzeletti, G. (1999) "Large Scale Testing with Pseudo-Dynamic Technique on Structures Provided with Energy Dissipation Systems at JRC-Ispra", *Proceedings of the 15th Post-SMiRT Conference, August 23 to 25, 1999, Cheju, Korea*

Magonette, G.; Renda, V. (1999) "Experimental Analysis of the Active Tendon Control of a Large-Scale Cable-Stayed Bridge Mock-up", *Proceedings of the IABSE, Conference, 2-4 June 1999, Malmö.*

Magonette, G.; Marazzi, F.; Tognoli, P.; Buchet, P.; Renda, V. (2001) "Experimental Analysis of Active Control of Vibration of a Large-Scale Cable-Stayed Bridge Mock-Up", *Proceedings of the 7th International Seminar on Seismic Isolation, Passive Energy Dissipation and Active Control of Vibrations of Structures, October 2-5, Assisi, Italy.*