Executive Summary:

The present report is the final MONICO Report containing the work performed during the whole (30 months) of the project lifetime, namely from 1 October 2008 until 31 March 2011. The report includes the WPs progress for the whole project duration, including targets, steps to achieve them as well as any issues, deviations and/or corrective actions from the plans.

Regarding the technical execution of the project all WP as successfully completed their respective objectives and tasks. Respectively, WP1 has concluded the two systems (BRILLOUIN and FBG) including the design and implementation of the related sensors as well as their testing and demonstration. The work in WP2, WP3 and WP4 has progressed as planned towards the assessment of the probabilistic, local, structural condition under normal, operating loads for the "Local Structural Conditions", "Local Seismic Capacity" and "Global Structural Condition" modules respectively including the suitable algorithms development, refinement and testing (and documentation). The methodologies and algorithms were tested having direct feedback from WP6 where the large scale tests were performed (and produced the relevant data). WP5 worked on The Expert System, the Data Base, the Knowledge Base and DSS and Package Integration. After the definition of the requirements, system scope and suitable DSS model, the conceptual design and the software architecture concluded into the implementation of the final prototypes of the Expert System and the Data and Knowledge bases (including user's manual and operational handbook). WP6 started from preliminary small scale specimens' experiments to analyse the structural behavior of typical circular tunnel linings. Through this, particular linings were designed followed with the design of the suitable sensorial units for the purposes. Towards the end of the project a large-scale experiment was conducted providing the whole system operation and testing as a whole. WP7 worked on the Knowledge Management and IPR protection. Inside this framework, it produced the final version of the Use of Foreground, while was also responsible for the project dissemination through conferences, events and other with the aid of the related material (demo CD, newsletters, leaflets, poster etc). In WP8 all the dissemination material was prepared including posters, logo, newsletters etc. Other actions included the training of the monitoring technologies (software and hardware) to the SME partners of the consortium.

Management and Assessment activities (WP9) ensured the proper overall project coordination, proper partners' communications, overview of technical activities, quality management, coordination of subcontracts procedures between the project SMEs and RTDs and also following of reporting/activities/deliverables of the project. Under this WP, issues were tackled. Organisation of several meetings has taken place including the preparation of related agendas and minutes.

Closing, all above activities have resulted into a smooth execution and successful closing of the MONICO project following the plans and project objectives.

Project Context and Objectives:

Fibre optic sensing is one of today's fastest developing technologies. One reason for this is that the costs of fibre sensors have been dropping steadily (in large part due to exceptional advances in fibre telecommunications technologies) and this trend will continue. Further, measurement capabilities and system configurations (such as wavelength multiplexed, quasi-distributed sensor arrays) that are not feasible with conventional technologies, are now possible with fibre sensors, enabling previously unobtainable information on structures to be acquired. One area where the above advanced technology can have an immediate impact in construction is in improving the current state-of-practice of structural monitoring systems. The importance of structural monitoring is growing due to a shift from construction costs to life cycle costs and lifetime performance including safety and use. This holistic approach in addition to monitoring technologies includes assessment methods. Fibre optic sensor technologies are finding growing application in the area of monitoring of civil structures. This has resulted in a growing field of fibre optic structural sensing in construction that is highly competitive and composed exclusively of SMEs. A study in the field by one of the SME proposers showed that 90% of those interviewed from the construction industry and the administration would like to outsource structural monitoring. It follows that companies in the fibre optic structural sensing field need to develop advanced methodologies and computer programmes for specific applications that based on the sensor information will assess the structural condition of the monitored facility. For this, these companies need expertise in structural engineering, earthquake engineering (in seismic prone areas), and structural reliability since there are uncertainties in measurements from inspections, materials' parameters and geometric properties and errors in materials' and structural models. Such expertise is presently not available in the fibre optic sensing industries.

Tunnelling activity is on the increase around the world, but it is not just the volume of work which is rising. The demands of modern transport networks mean that tunnels are longer and wider than ever before and being driven through increasingly difficult ground conditions. Moreover, several planned tunnels are in countries of high seismicity and a good part of the tunnel kilometers will be under densely populated areas and require very high standards of safety. To the above one should add that today's tunnel environment is characterized by high user demands, stretched budgets, declining staff resources and greater operational complexity necessitating the development of asset management plans that are based on accurate and timely assessment of the structural health of tunnels. Accordingly, the new niche market of tunnel continuous monitoring and assessment should be among the first markets to be targeted by the SMEs in the fibre optic structural sensing field. There is an increasing awareness of the sensitivity of tunnels to seismic activity (tunnels have experienced significant damage in recent large earthquakes including the 1999 Kocacli, Turkey earthquake, the 1999 Chi-Chi, Taiwan earthquake and the 1995 Kobe, Japan, earthquake). Moreover, the damage to the tunnel structure is difficult to assess and a damaged tunnel that has survived the major earthquake might not have the capacity to survive consecutive seismic aftershocks. Such aftershocks take place within few hours of the earthquake and have been reported to have an intensity of up to 90% of the earthquake intensity.

Tunnel primary linings are mostly constructed of reinforced concrete (r.c.). Most vulnerable are lining cross-sections under inhomogeneous loading, e.g. cross-sections located in regions of transition from one type of soil to another. Included are the tunnel entrance and exit. Included also in the old cities of EU are metro cross-sections that on one side step on ancient ruins. For instance in Athens such cross-sections can be found on the average every 200 meters. All structures undergo deformations under the effects of loads or changes in the constituent materials. The deformations of any structure (tunnels, bridges, etc.) contain a lot of information about its health state. By measuring these deformations it is possible to analyse the loading and ageing behaviour of the structure and assess its safety. To ensure the safety of vulnerable tunnel cross-sections or sections where very high standards of safety are required, fibre optic sensors providing a real-time, wireless and remote deformation sensing capability, need to be integrated with software that will collect and process the signals and assess the structural reliability of the lining. In regards to proactive maintenance measured deformations can be converted to strains, curvatures, deflections, stresses, bending moments and axial forces which can be monitored so that they do not exceed limit values. Regarding earthquakes: The philosophy of earthquake resistant design is to mitigate extensive damage rather than to prevent its occurrence. Elastic response provides a poor measure of susceptibility to damage. The damage done to a cross-section during strong motion excitation depends primarily on the energy transmitted and dissipated by the cross-section during inelastic cycling. Only by recording and analyzing the structural response during the latter cycling can an accurate evaluation be made of the remaining dissipative energy capacity of the cross-section before the limit state is being reached.

In the EU funded project TUNNELLING, TECNIC developed an energy-based theory of seismic failure for reinforced concrete tunnel lining cross-sections based on the history of deformations during the earthquake derived from fibre optic measurements. It was deterministic and limited to local failure. Deterministic evaluations leave no room for tolerances for errors in data from non-destructive evaluations, variations in materials and the relevant geometry and errors in modeling material and structural behaviour. Hence, the deterministic evaluations obtained without consideration of uncertainty could lead to unreliable results. Accordingly, reliability-based evaluation methods are more appropriate. Furthermore, local failure does not necessarily result in global failure (collapse) of the monitored cross-section. Thus, the probabilities of both local and global failure need to be determined. New technologies are being developed continuously in the optical sensing area which is one of the fastest developing technologies. What is needed at this point is that existing and emerging fibre optic deformation monitoring technologies be evaluated and optimised so that alone or in combination can provide optimal performance in tunnel structural sensing under operating and seismic loads. The SMEs in the fibre optic sensing field do not have the extra manpower and facilities for the above.

The overall objective of the proposed research is to provide the SMEs in the group with an integrated package that will include an optimised fibre optics sensing system for the continuous monitoring of deformation and a DSS for the assessment of the structural condition of reinforced concrete, transportation, primary tunnel linings under operating and seismic loading.

To accomplish the above, specific scientific and technical objectives of this work are:

1. To provide optimised fibre optics based sensing system for r.c. tunnel linings that can be embedded in concrete for the life cycle measurement of deformation, that measures fast events (seismic disturbances) and that transmits information to a remote base using a wireless interface. A Sensor Data Processing Module (SDPM) will be developed that will be part of the monitoring system in order to filter out noise and erroneous data and present it in a way that is useful and convenient to the user. To elaborate further, the SDPM will be a software component to render the data to the appropriate format in order to be fed to the expert system. A processing of the sensors data will ensure the compatibility of the format for processing by the structural condition assessment software.

At the very minimum the following systems will be evaluated in regards to continuous tunnel monitoring, optimised and possibly combined:

* A Bragg grating fibre optic based monitoring system. This system will permit at least 2×8 gauges, each between 200 mm and 2000 mm long, to be put on the same fibre and each gauge will include at least 4 conventional, high reflectivity apodised fibre Bragg gratings (FBG). The resolution of each specific sensor is expected to be around 1-5 $\mu\varepsilon$ in strain terms or 1-5 pm in wavelength terms. Two ~ 30 m long systems will be installed inside the inner and outer linings of the tunnel. The environmental temperature of the sensors will be monitored and the measurements compensated accordingly. The remote interrogation system will perform, with the aid of a CCD, a spectrum analysis of the light reflected by the FBGs and decode the Bragg wavelength shifts in terms of the strain acting on the gauge. A broadband (~75nm) SLED light source will accomodate the full spectral range of FBG wavelengths. The interrogation system will support 2 channels, the inner and the outer sensor systems, simultaneously using an optical switch.

* A distributed fibre optics sensing system based on the principle of Brillouin scattering. Brillouin scattering is a fundamental process of inelastic light scattering which occurs due to the interaction of light with acoustic waves (phonons) of an optical medium. The backscattered light of the Brillouin process is red-shifted from the frequency of the incident light and this shift is proportional to the strain and temperature at the certain part of the medium from which the backscattered component arises. Using pulsed light and optical time domain reflectometry (OTDR) measurements, the Brillouin shift can be resolved in space along the fiber (medium) thus a distributed (almost continuous) sensing of strain and temperature along the fiber is possible. The interrogator of the Brillouin sensing system is a sophisticated coherent detection device that is able to measure the beat frequencies arising from the detuning between the incident and backscattered light. The space resolution of the

system is proportional to the duration of the light pulses. It can be as low as 1m or even lower if a special mounting technique of the fiber is employed and the strain resolution can be as low as 5με.

Both of the above approaches have certain advantages and disadvantages. They will be identified, evaluated and optimised, so that alone or in combination can provide optimal performance in structural sensing. Briefly, the main advantage of Brillouin technique is the capability of continuous strain and temperature measurements along a simple and inexpensive commercial fiber cable that runs along the entire structure to be monitored. Though, our proposed analysis, will refer to specific sections of the installed fiber, it gives the ability to monitor any point on the fiber line, allowing for the fine tuning of the section to be monitored. However, the spatial resolution of the Brillouin method is restricted by the pulse width to approximately 1m. Moreover due to the inherent characteristics of the Brillouin phenomenon (low backscattered light power) the rate at which measurements can be obtained is lower compared to an FBG system. On the other hand FBG sensing systems are more complicated in installation due to the multiple gauges required for monitoring different points of the same structure but lend themselves to high data acquisition rates. The complexity and the cost of a Brillouin interrogator is also considerably greater compared to the much simpler FBG interrogator.

2. To develop a methodology for the probabilistic assessment of the local structural condition of the r.c. monitored sections in the tunnel lining cross-section under operating loads based on measurements of deformation.

3. To extend the deterministic energy-based theory of local seismic failure for reinforced concrete structures devised by TECNIC to a probability-based assessment of local seismic structural reliability.

4. To develop a methodology for the probabilistic assessment of the global structural condition of the r.c. lining cross-section based on the local, probabilistically defined, conditions in the monitored lining sections.

5. To evaluate the methodology in '4' via non-linear finite element analyses.

In '2', '3' and '4' above account will be taken of errors in data from the fibre optic sensors, variations in materials' parameters and the relevant geometry and errors in the modeling of materials and structural behaviour.

6. To provide an integrated package for tunnels for health monitoring and safety assessment under routine operation and seismic forces. It will include:

* The system in'1'.

* The 'Local Structural Condition' Module. This Module, which is a software implementation of the theory in '2', will receive as input from the sensing system measurements of deformation according to some schedule and will process it to derive the corresponding strains, curvatures, stresses, moments and the axial force and to assess the probability that defined limit states have not been exceeded..

* The 'Local Seismic Capacity' Module. This Module, which is a software implementation of the theory in '3', will receive as input from the sensing system the deformation time history during an earthquake and will process it to assess, probabilistically, the remaining dissipative capacity of the monitored sections before the limit state is being reached.

* The 'Global Structural Condition' Module. This Module, which is a software implementation of the theory in '4', will receive input on local conditions from the above Modules in order to derive, probabilistically, the global structural condition of the tunnel cross-section. This Module will signal a warning if the tunnel is unsafe or if, in the case of an earthquake, might not survive expected aftershocks.

* Deterministic versions of the above Modules will also be provided. Moreover, these Modules will be usable with the existing sensing systems of the SMEs in the group as well as with other sensing systems that can provide tunnel deformations.

* A Data and Knowledge Base that will contain domain knowledge (represented in the domain modules) and system knowledge (i.e. rules governing the coordination of the system modules). The Data Base will include sensor data and data on tunnel records (e.g. amount and type of steel reinforcement).

* An Expert System. This system will coordinate the other modules and sub-modules and will act as an intelligent intermediary between the users and the results that will be obtained.

7. To experimentally evaluate the sensing and data acquisition system in '1' and the predictive ability of the theory of seismic failure in '3'.

Project Results:

WP1 Monitoring System. Wireless Communication Capability (ICCS):

General Objectives

* Development and production of a fibre optics based deformation monitoring system that can be embedded in concrete and report at seismic frequencies.

* Development and production of interrogation equipment for the above system.

* Development and production of the Sensor Data Processing Module (SDPM) which will be part of the monitoring system.

* Provision of reliable wireless communication capability in supporting the project information transfer requirements under normal conditions and in the event of an earthquake.

Work progress towards objectives:

* Deformation Sensors: The complete set of technical characteristics for the fabrication of FBG sensors was determined, meeting the requirements of the project, in terms of glass materials, grating parameters (pitch, strength, apodization), wavelengths, sidelobes level, strain and temperature sensitivity. A considerable effort was also devoted to the design of the gauges (SmartRod-style steel bars) that will enclose the FBG sensors. A redesign was required in order o increase the measurable strain range close to the concrete damage limit. This affected the number of sensors per line and the switching scheme.

* Sensor Data Processing Module: Procedure and algorithm have been developed to transform Bragg wavelength shifts to strain information and compensation for the temperature dependence of measurements.

* Interrogation Unit: The specifications of the light source (LED) that will illuminate the FBG arrays in terms of wavelength range and power have been developed. Analysis and details of the couplers directing the reflected light to the detecting unit has also been executed. Specifications of the CCD-based spectrum analysis of the reflected light in terms of resolution and sensitivity are complete.

* Wireless Communication Capability: The work has included hardware and software design: wireless modem, WiFi equipment, hub and router, protocol and interrogation routines between LabView environment and router. Two possible scenarios/options were developed regarding Ethernet or USB based connection of the interrogation unit.

* All objectives distributed among the tasks 1.1-1.4 were achieved as far as the design of the FBG sensors-based deformation monitoring system. The system was completely finalized and approved by the civil engineers partners.

* Problems related to the mounting of gauges to the lining so as to avoid techniques that may damage the sensors (welding) were solved through cooperation with partners experienced in civil structures.

* Special attention was given to the required triggering of data recording in the event of an earthquake ("awake" signal): survey on seismic switches and sensors, accelerometer and geophone technology. The discussion and survey concerning the required triggering of data-recording in the event of an earthquake ("awake" signal) has lead to this solution: the transient data provided the FBG sensors will be processed by the software (developed by RISA) in order to detect an abruptly increasing strain envelope. Thus, no additional earthquake triggering device (e.g. geophone) would be needed, which is beneficial in terms of cost and maximizes the utility of our sensors.

* A wireless communication between FBG interrogator and the end user pc was established employing a USB extender. This module was chosen as the simplest solution for wireless communication, however error-free communication was achieved at a low data rate, inadequate to support continuous flaw of interrogator generated data. The well-established Ethernet technology is currently setup as the final solution for the wireless system communication.

* A first round of experimental calibration and validation of the FBG sensors completed to obtain essential results on the sensors performance. Full sensor characterization in the Material Tester test-bed was completed.

* Regarding the Brillouin Optical Time Domain Reflectometry (BOTDR) fiber sensor types were selected and a preliminary coil-shaped sensor configuration was setup, in order to reduce the spatial resolution of the technique.

* The issues of the wireless communication data rate were solved in cooperation with AOS. USB-Ethernet solution was complete while a second pc-pc Ethernet communication was also evaluated as fall-back position.

* Intense collaboration between ICCS, AOS and UNITN allowed for an improved version of FBG sensors with better mounting features that exhibit increased tolerance to sensor deformation.

* Development of spiral shaped BRILLOUIN sensors and (in-lab) characterization.

* Completion of D1.2: "The SDPM, the Interrogation Unit and the Wireless Transceiver Module" (M22).

* Brillouin Optical Time Domain Reflectometry (BOTDR) technology inherent restrictions were identified in spatial resolution, operational frequency and strain sensitivity/ dynamic range. Custom configuration was accommodated in order to match/compensate for these operational characteristics. Please check D1.2 and D1.3.

* During the last reporting period, ICCS performed the characterization of the BRILLOUIN sensors.

* ICCS (in cooperation with AOS) prepared the FBG and BRILLOUIN sensors that were installed in the final test ring (in UNITN labs). Feedback was consolidated from the previous tests to improve and provide the optimal sensor solutions for the case.

* ICCS in cooperation with AOS and UNITN aided the installation of the sensorial (FBG and BRILLOUIN) systems to the UNITN laboratory (final tunnel test ring).

* Completion of the deliverable D1.3 - "embedded deformation sensors evaluated at the structural lab and refined.

Corrective actions taken/suggested:

* In the 4th MONICO meeting in Padova, partners agreed on taking a list of actions in order to solve the problem with OSMOS. Please refer to the MONICO meeting minutes. Partner OSMOS was formally removed from the consortium.

Contractors that worked in WP1: ICCS, OPTRONICS, AOS, GHT, TECNIC, RISA

WP2 The 'Local Structural Conditions' Module (RISA):

General Objectives:

* Development of a methodology for the probabilistic assessment of the structural reliability of monitored reinforced concrete sections in a tunnel lining subjected to operating loads, based on measurements of deformation.

* Software implementation of the above in the 'Local Structural Condition' Module.

Work progress towards objectives:

* A methodology has been developed, as planned, for the assessment of the probabilistic, local, structural condition under normal, operating loads. It has been assumed that geometric properties (that is, the height of the cross section, distance between rebars and rebar covers) will be measured with a sufficient degree of accuracy when the sensors are installed. It has also been assumed that the measurement error of the sensors is negligible next

to other uncertainties. Based on the above the four following material variables are considered as random variables: Yield Strength of Concrete in Compression, Ultimate Strain of Concrete in Compression, Yield Strength of Steel and Modulus of Elasticity of steel.

* A methodology has been developed, as planned, for the stochastic assessment of the local seismic capacity based on strain measurements. In this case in addition to the random variables above, DA, the allowable value of the energy ratio damage index D, has also been treated as a random variable.

* Requirements and specification of the module were successfully completed.

* Testing and refinement of the module was executed on time followed by the related documentation.

* Finishing Task 2.3.4 Documentation.

* Deliverable D2.2 finalization

Corrective actions taken/suggested:

No corrective actions needed.

Contractors that worked in WP2: OPTRONICS, AOS, GHT, TECNIC, RISA

WP3 The 'Local Seismic Capacity' Module (RISA):

General Objectives:

* Development of a methodology for the probabilistic assessment of the seismic structural reliability of monitored reinforced concrete sections in a tunnel lining subjected to seismic loads based on measurements of deformation.

* Software implementation of the above in the 'Local Seismic Capacity' Module.

* To develop a methodology for the stochastic assessment of the local seismic capacity based on strain measurements.

* Development of the requirements and specifications of the software package based on the methodology in Del. 3.1.

* Start working on the design and implementation of the software package.

Work progress towards objectives:

* A methodology has been developed, as planned, for the stochastic assessment of the local seismic capacity based on strain measurements. In this case in addition to the random variables above, DA, the allowable value of the energy ratio damage index D, has also been treated as a random variable.

* Requirements and specification phases successfully completed during the second year of execution of the project while the design and implementation phases started immediately afterwards.

* The testing and refinement phases concluded the actual algorithms development phases.

* Documentation (Task 3.3.4) has been completed.

* Finalization of Deliverable D3.2.

Corrective actions taken/suggested:

No corrective actions needed.

Contractors that worked in WP3: OPTRONICS, AOS, GHT, TECNIC, RISA

WP4 The 'Global Structural Condition' Module (TECNIC):

General Objectives:

* The objective of this WP is to assess, both deterministically and probabilistically, the degree of global damage of the monitored lining cross-section under normal operating and/or seismic loads

Work progress towards objectives:

* A methodology was developed and evaluated, as planned, that, based on local damage under operating conditions, can predict, deterministically and stochastically, the global stability of the monitored cross-section.

* While working in WP4 the RTD performers realized that based on the measured deformations at specific points on the monitored tunnel cross-section under operating loads, they can, through back analysis, assess the applied external loads on the tunnel (that vary as a function of time and are unknown) and tunnel stability. This approach is novel and will provide invaluable information to tunnel owners and tunnel researchers. To this target the requirements and specifications were completely done and the design and implementation of the software package has started.

* The requirements and specification task was successfully completed while the design and design and implementation started on schedule.

* The testing and refinement task started and completed successfully including testing, integration, identification of problem areas and upgrading and refinement.

* The documentation task started also on time having as a major objective the contribution to system guide and user manual.

* During the last six months of the project the documentation task 4.3.4 was completed

* Completion of deliverable D4.2 - "Module 3 Evaluated at the Structural Lab and Refined".

Corrective actions taken/suggested:

No corrective actions needed.

Contractors that worked in WP4: OPTRONICS, AOS, GHT, TECNIC, RISA

WP5 The Expert System, the Data Base, the Knowledge Base and DSS and Package Integration (RISA):

General Objectives:

* To design and deploy a system architecture that is flexible (so that it can be adapted to different types of fibre optic sensors), scalable (so that it can include into the future additional functions, e.g. selection of rehabilitation measures) and modular (so that that it can include additional type of measurements, e.g. corrosion measurements).

* To develop the Expert System, the Data Base and the knowledge Base.

* To integrate all modules in the DSS.

* To integrate the DSS with the sensing and data acquisition system. Moreover, to provide appropriate interfaces so that the proposed DSS can be used with the existing monitoring systems of the SMEs in the group.

Work progress towards objectives:

* The development of a common understanding of the system's scope and desired behaviour has been accomplished.

* A methodology has been defined, as planned. Having reviewed the available methodology, it has been decided that the overall development approach for the MONICO DSS will be the adopted adapted waterfall model, which includes Analysis, Design, Development, Testing and Evaluation. The chosen data access application and programming language will be Microsoft Access and Java.

* A specification for the Expert System and the Data and Knowledge Bases has been set. The translation of the user requirements into specifications that describe the conceptual models for the Expert System and the Data and Knowledge Bases and how to implement them. The requirements have been transformed into a conceptual design and the best software architecture that is scalable and modular and permits future expansion of the Expert System and the Data and Knowledge Bases to accommodate additional applications.

* Design and implementation of the Expert system and the Data and Knowledge Bases. The purpose was to set out the design of the modules of the Decision Support System. As the design has advanced with the clear longer-term goal of module integration, both it and the implementation methodology reflect an explicit preparation for the integration stage of the software development life-cycle.

* Software implementation and development of the prototypes of the Expert System and the Data and Knowledge Bases.

* The design and implementation task (t5.3.3) was successfully finished towards the end of the 2nd year of the project.

* The integration task started in year 2 and by the end of the same year it was almost finished (90%).

* System documentation started as planned during the second year.

* Finished integration: It involves integration of all modules in the DSS and integration of the DSS with the sensing and data acquisition system (Task 5.4)

*	Finished Global System Testing and Consolidation: It involves testing and refinement of the overall DSS and includes test planning, global and extensive system testing, analysis of results and upgrading (Task 5.5)

*	Finished Documentation (Task 5.6)

*	Finalization of deliverables D5.3 and D5.4

Corrective actions taken/suggested:

No corrective actions needed.

Contractors that worked in WP5: ICCS, OPTRONICS, AOS, GHT, TECNIC, RISA

WP6 Laboratory Evaluation of the Performance of the Condition Monitoring System and the Predictive Capability of the Theory of Seismic Failure (UNITN):

General Objectives:

*	To assess in a structural laboratory the performance of the condition monitoring system on reinforced concrete specimens (substructures) representative of a tunnel lining

*	To calibrate against novel monotonic, cyclic and dynamic test results the energy-based theory of seismic failure

*	To validate the predictive capability of the energy-based theory of seismic failure and the global structural condition module

Work progress towards objectives:

*	This WP officially was to start on M16. However an Internal report on the design of specimens to be tested by UNITN was produced quite earlier. In detail, possible substructure and demonstration tests are presented devoted to the calibration of models and to the investigation of a typical design case where seismic forces can be greater than the ones obtained through static analysis.

*	UNITN started parts of activities of WP6 after the co-ordinator of MONICO, in agreement with the remaining partners, proposed to test a full scale specimen of a tunnel

lining in the UNITN laboratory. This test for its own nature is complex and risky, and unfortunately is unique. As a result in order to identify the optimal fiber attachment to the rebars, the plastic hinge length and the experimental material stress-strain constitutive laws as well as the moment curvatures diagrams, UNITN proposed to perform some preliminary tests on tunnel substructures, to be carried out.

* WP6 started to analyze the structural behavior of typical circular tunnel linings according to recent research works. The determination of actions, which the structure is subjected to, as well as their distribution represent main steps towards an adequate and significant specimen design. Thus, both static and seismic analyses were performed, by using common realistic size and materials for the lining and typical soil, depth and water table level values. Since the project is devoted to the detection of damage owing to seismic events, we designed the tunnel lining so that seismic loadings result to be critical. We found that actions are sinusoidal along the curvilinear coordinate of the transverse section; moreover, we identified that in correspondence of the maxima, tunnel portions of about 1 m long could be considered subjected to constant bending moment. Hence, specimens representative of tunnel lining substructures to be subjected to monotonic and cyclic 4-point bending tests were reckoned to be suitable for our purposes.

* Due to the concrete flexural behavior associated with high levels of stress distribution, e.g. owing to an earthquake, plastic hinges may form entailing large localized deformation associated with damage. The plastic hinge length depends on many factors and, therefore, it is important that FBGs be located within this length. Furthermore, cracking also occurs and this causes the so-called tension stiffening effect, i.e. tension peaks in the rebars in correspondence to cracks. This means that a FBG bonded to the concrete may be affect by this local phenomenon. Hence, the material characterization plays a central role in the FBG packaging design. Since, the preliminary tests also aims at identifying the optimal fiber attachment, two FBG packages have been conceived on the basis of the plastic hinge length estimate and employed in each instrumented specimen in order to measure strains at the two longitudinal rebar levels: i) FBGs bonded to the concrete and ii) FBGs unbounded to concrete. The latter system allows measuring mean strains in the plastic hinge zone, by eliminating any tension stiffening effect. Moreover, the packaging has been designed in order to be easily attached to the rebar cage.

* Through the structural analysis we designed the substructure specimens and we chose the test typology.

* In order to identify the optimal fibre attachment, we designed the FBG packing on the basis of material characterization.

On the basis of the numerical analyses carried out in first year, UNITN found that actions are sinusoidal along the curvilinear coordinate of the lining tunnel transverse section; moreover, UNITN identified that in correspondence of the maxima, tunnel portions of about 1 m long could be considered subjected to constant bending moment. Hence, specimens representative of tunnel lining substructures to be subjected to monotonic and cyclic 4-point bending tests were reckoned to be suitable for our purposes. Since, the material characterization plays a central role in the FBG packaging design, we decided to perform 3 preliminary tests with also the aim of identifying the optimal fibre attachment. In detail, only one specimen was instrumented with FBGs, the other two were exploited to set the parameters of the loading protocol and to establish an optimised traditional instrumentation, whose data were compared with those obtained through the fibre sensors. Two FBG packages were conceived on the basis of the plastic hinge length estimate and employed in the instrumented specimen in order to measure strains at the two longitudinal rebar levels: i) FBGs bonded to the concrete and ii) FBGs unbonded to concrete.

At the end of September 2009 UNITN received from AOS the fibre packaging and casted the specimens. At the end of November 2009 UNITN performed the tests: 1) monotonic without fibres; 2) cyclic according to the ECCS (1986) protocol without fibres and 3) cyclic according to the ECCS (1986) protocol with optical fibres. After the tests we elaborated the data and the main findings related to the fibre optic sensor system are:

* The substructures exhibited ductile behaviour with large deformations in the plastic range associated with high energy dissipation. This implies that the structural design is suitable for seismic loading.

* Though both unbonded and bonded packaging solution should allow fibres to measure 1% strain, from the results we noted that fibre optic sensors were not capable to measure reliable strains after reaching about 0.2% strain. In fact, the bonded solution with increasing displacements unexpectedly read decreasing strains. From measurements we did not have accurate information on the performance of the unbonded solution, hence, it is recommended to test the unbonded solution or another packaging solution.

* In addition, the measurement of strain on short lengths can prevent an effective measure of the mechanical behaviour, i.e. the strain measure may occur in an uncracked concrete portion that entails smaller deformation values than the actual average ones. In this respect, unbonded fibres might provide more accurate values. Needless to say that steel deformation values less than 1% are expected in tunnel linings out of fault regions.

These preliminary outcomes aided the partners to select optimal solutions in terms of optical sensors and type of packaging to be installed in the next 3 tests.

During the second semester of the second reporting period UNITN designed and cast three substructures 3000 mm long and 1000 m wide characterized by a section of 200 mm. In detail, these specimens will be subject to:

* a cyclic test with FBGs fiber sensors (CF1), where the fibers will be externally installed;

* a cyclic test with FBGs fiber sensors (CF2), where the fibers will be both embedded in the specimen and externally installed;

* a cyclic test with Brillouin fiber sensors (CB1) that will be externally installed.

The design of the concrete ring was made too. The specimen was characterized by a ring endowed with 4800 mm diameter and a section of 200 mm. The specimen will be endowed with 32 FBG and 16 Brillouin fibers. Eight sections will be monitored and, in each of them, both technologies will be adopted. Cyclic loading was considered with a δy of about 6mm.

During the last six months of the project, three tests on substructures 3000 mm long and 1000 m wide characterized by a section of 200 mm were executed as follows:

* a cyclic test with FBGs fiber sensors (CF1), where the fibers were externally installed;

* a cyclic test with FBGs fiber sensors (CF2), where the fibers where both embedded in the specimen and externally installed;

* a cyclic test with Brillouin fiber sensors (CB1) that were externally installed.

For the CF1 specimen, the maximum strain was almost 1%; AEP and fiber sensors showed that the substructure reached the plastic range, whilst standard strain gauges were broken.

For the CF2 specimen, the maximum strain was almost 0,8% for the external fibers, whilst almost 1,3% for the internal fibers. This time AEPs, fibers and strain gauges showed that the substructure didn't reach the plastic range but remained in the elastic range.

With regard to CB1, the specimen reached displacements values at about 4y, i.e. 76 mm, with curvatures of about 0.5 1/m. Brillouin fibers performed significantly well.

In general, the fibre optic system externally installed in test CF1 allowed the plastic moment to be identified. In fact, the fibres read up to the 3rd cycle at a displacement of 2y - i.e. 38 mm - measuring strains up to 1%, thus detecting a hysteretic behaviour. However in the CF2 test, the external fibers reached lower strain values. The method used to unbond the rebar of the second test campaign resulted to be more suitable for characterizing the average strain in the plastic hinge zone with respect the one employed in the first test campaign.

Finally, it was decided that the sensor configuration for the ring test should include both fibre technologies, i.e FBGs and Brillouin, in each monitored section.

The final test on the concrete ring was carried out the 3 February 2011. The specimen was characterized by a ring endowed with 4800 mm diameter and a section of 200 mm. The specimen was endowed with 32 FBG and 16 Brillouin fibers. Eight sections were monitored and, in each of them, both technologies were adopted. Cyclic loading was considered with a δy of about 6mm. The concrete failure was reached at section 8; in detail this failure happened at the first cycle of $4\delta y$, i.e. almost 25 cm. The ring exhibited a ductile behavior associated with a high energy dissipation. Both FBGs and Brillouin sensors worked well and were capable to trace the evolution of inelastic mechanisms.

The data provided by the overall test program allowed the methodology for the deterministic and probabilistic assessment of the structural condition of a monitored tunnel reinforced concrete cross-sections to be calibrated and validated. This methodology based on the recorded strains of sensors installed both on the inner and outer transversal reinforcing bars in the eight critical sections will generally involve: the estimation of section internal forces; the external loads applied on a tunnel lining; the actual values of estimated damage indices. The structural assessment will concerns the behavior under seismic loadings and the long term behaviour under normal operating conditions.

Corrective actions taken/suggested:

No corrective actions needed.

Contractors that worked in WP6: AOS, GHT, TECNIC

WP7 Knowledge Management and IPR Protection (GHT):

General Objectives:

- To secure by copyright protection the software that will be developed in the project.
- To file for patents for the optimised sensing system.
- To produce the plan for the use of the foreground

* To produce a brochure and a CD demo for the DSS and the monitoring system that will be used to present the results to major potential customers

* To present the results to major potential customers.

Objectives for the current period:

* Identifying the team in charge of WP

* Setting up the deliverables, the plan for the use of foreground and market analysis template

* Releasing of actual version of market analysis template to partners.

* Collecting exploitation input from partners;

* Releasing of draft version of Plan for the Use of Foreground.

Work progress towards objectives:

* WP7 started handling IPR issues including securing by copyright protection either for software which will be developed and for optimized sensing system which will be produced. GhT also started to set a plan for the use of foreground together with the other SMEs. Moreover we've started to talk with some major customers about the results of this project for mutual benefits.

* During the first year of the execution, the draft version of the plan for the use of foreground was implemented. The document reports either the dissemination and exploitation activities to be carried by consortium members, including the different channel to diffuse as much as possible the knowledge of project results toward scientific and industrial community. We've also put a list of potential target groups which could be the final users of the project. Finally WP7 started to build a brochure and CD demo for customer presentations.

* The plan and the dissemination activities realized so far are reported in D7.1 "Plan for the Use of the Foreground".

* The draft version of plan for the use of the foreground has been produced during the 2nd semester by the WP7 leader, with the support of SMEs. In the last 3rd semester, the involved partners added other targets for the dissemination activities and also potential customers in the data base of the plan for the exploitation of the project results.

* In the last semester GHT also proceeded in defining the different issues which will take to the final version of plan for the use of the foreground, i.e. adding new references regarding potential customers and also identifying strategies for an agreement between SMEs addressed to the ownership of the monitoring system and for DSS.

* During year 2, the design of the CD demo for the DSS and monitoring system to present the results to major potential customers started. Also, the brochure was to be designed for same purposes.

* SMEs started to disseminate the preliminary results of MONICO to the most relevant potential customers included in the data base of the draft of plan for the use of the foreground, through periodical updates via mail and newsletter. Also, the suggestions raised by these contacts help us in identifying new potential markets for MONICO results.

* Through conferences and symposia attending during the project duration, MONICO partners have been able to increase the knowledge of project outcomes, either towards industrial users, researchers and designers.

* During the second year of the project the WP7 leader has been collecting from the other project partners new improvements, remarks and ideas for producing the final version of the plan for the use of the foreground. Besides, the feedback from potential customers has been quite positive and we're confident about the continuity of such interest also for the new results obtained by RTD performers which are added continuously.

* The drafting of other dissemination tools, like CD demo, brochure and also next newsletters also started during year 2.

* The collection of fundamental outcomes by the RTDs involved in the project has pushed the knowledge management activity towards potential customers it was quite sure that the interest of potential customers would increase more and more.

* A dissemination plan for the whole duration of the project has been drawn. The plan and the dissemination activities realized so far are reported in D7.1 "Plan for the Use of the Foreground (Draft)".

* Creation of SME's agreement report on the ownerships of the MONICO results. Please refer to deliverable D7.2. (Action executed in collaboration with all project SMEs).

* Creation of deliverable D7.2 - use of foreground - final version.

* Circulation of MONICO results to potential customers as these reported in D7.2.

* Development of MONICO Demo-CD.

* Design and development of the MONICO final brochure.

* Development of MONICO demonstration video to be included in the demo CD.

* Distribution of dissemination and demonstration material to potential customers.

Corrective actions taken/suggested:

No corrective actions needed.

Contractors that worked in WP7: OPTRONICS, AOS, GHT

WP8 Training and Dissemination of Results (GHT):

General Objectives:

* To disseminate the existence of the project and its results and achievements to the scientific community but mostly, through a market oriented approach to companies that provide structural monitoring services, agencies that own and operate tunnel facilities, tunnel rehabilitation contractors, tunnel designers, tunnel contractors, providers of fibre optic sensing services, insurers, officers in public safety agencies, representatives of relevant associations and societies, such as the Fibre Optic Association, The Optical industry Development Association, the International Tunnel Association, The Construction Management Association, the International Tunneling Insurance Group and others.

* To develop an interactive and user friendly web site to inform the general public and all stakeholders about MONICO.

* To organise a workshop that will focus on the application and end-users.

* To train the technical and managerial staff from the participating SMEs on the use of the DSS and the monitoring system.

Objectives for the current period:

* To disseminate the existence of the project and its results and achievements to the scientific community.

* To develop an interactive and user friendly web site to inform the general public and all stakeholders about MONICO.

Work progress towards objectives:

* The MONICO logo was developed and approved by the consortium. The logo is used to identify all project results including deliverables, dissemination material, scientific posters, etc.

* In order to facilitate the data communication among partners an ftp site was implemented restricted only to the consortium members. The ftp server will also serve as a storage place for all internal reports, deliverables, milestones and other project documents/files.

* The project's website was designed and implemented at www.monico-eu.org. The website includes information over the project's mission, objectives, technological approach, deliverables, latest news and contact information. The website will be continuous updated throughout the project's lifetime. Partners' logo, website and any other supportive material to be included in the project web site and dissemination material was gathered.

* Two issues of MONICO electronic newsletter were issued, at month 6 and 12 of the project, introducing MONICO project and presenting the work progress during the first year of project lifetime. The necessary material was requested and gathered from the relevant partners. The newsletters have been uploaded at the web-site.

* A mailing list has been implemented which is composed of people interested on the project's activities. The mailing list members will regularly receive updates on the project in the form of newsletters.

* MONICO leaflet and poster were developed. The design and graphical elements used were in line with the logo and the ones used for the web-site. The leaflet and poster were handed-out at conferences, workshops as well as important related events.

* In order to facilitate the selection of the appropriate edition or event to publish the project's results the dissemination responsible periodically issues an event calendar which includes events of special interest to the project.

* Our first aim, to disseminate the awareness of existence of MONICO both toward scientific community and potential industrial users, is pursuing continuously, being one of the first objectives of WP8. That was carried out through different ways, but all of them are with a market oriented approach. Also, the Consortium set the conferences, workshop and exhibits to attend for dissemination purposes; further it created the basis for organizing a final workshop which will release the final outcomes to potential end-users.

* The last newsletter has been released at the end of 2010, so all the potential customers included in the mailing list have been able to realize the valuable developments obtained during the last period. The document describes the MONICO proposal, giving an overview of monitoring technologies implemented in the project, introducing the DSS (Decision Support System) which is compound by the ES (Expert System) and the Data Base of sensor data and tunnel records and finally an approach for deterministic and probabilistic assessment. We've also examined sensor and material performances used in the project and finally described some tests on small scale specimen.

* The final newsletter and Project brochure were distributed to the list of potential customers.

* Further potential customer opportunities (in cooperation with all SMEs) and improvement of customer data base were investigated and improved.

* Towards the end of the project the MONICO workshop was organised.

* The RTD partners performed training of the monitoring technologies and software modules, through on-site meetings during the pre-final and final tests and other meetings, workshop etc.

* Website updates regarding project deliverables, recent outcomes, publications and recent updates were performed during the last period of the project.

* Following activities to submit project results into related conferences and journals (please refer to D7.2 for details).

Corrective actions taken/suggested:

No corrective actions needed as the delay was not crucial.

Contractors that worked in WP8: ICCS, OPTRONICS, AOS, GHT, TECNIC, RISA

WP9 Consortium Management and Assessment of Progress Results (ICCS):

* Overall project coordination. Communication with partners at all levels (WP leaders, Task leaders, and partners).

* Overview of all technical activities.

* Coordination of the subcontracting procedure between project SMEs and RTDs. A template for subcontracting was prepared and distributed to the SMEs. The SMEs provided feedback and the template was agreed and signed by the three SMEs. The actual agreement has been included in deliverable D7.2.

* Regarding the issues with the defaulting partner (OSMOS), ICCS as the Project Coordinator and in cooperation with the Project Officer (EC), has followed all the legal and formal steps to exclude the partner and replace it by OPTRONICS SA. The coordinator closely collaborating with the Project SMEs have analyzed various alternatives and the most proper partner was identified always ensuring high expertise as needed and fitting into the project needs as well.

* Preparation of agenda, organisation and coordination plenary meeting on the 10-11 March 2010.

* Preparation of agenda, organisation and coordination of kick-off and 1st Plenary meetings.

* Preparation of kick-off and 1st Plenary meetings minutes.

*	Coordination of financial and technical contributions for the preparation of the 1st, 2nd and 3rd Interim Activity Reports. Preparation of the relevant templates and distribution to partners.

*	Close follow-up of reports/activities/deliverables deadlines and responsible partners.

*	The Quality Control Procedure for the project is defined from the beginning of the project. The Quality Manual sets the rules and procedures for document and data control, reporting and scheduling of dissemination events and reviewing of project deliverables. The manual includes templates for official MONICO documents and naming conventions.

*	Coordination of review process (executed off-line), final review (also executed off-line) and submission of deliverables.

*	Preparation of the technical meeting in Dresden (27 July 2010).

*	Initial organisation for the next Plenary meeting (09-10 November 2010).

*	Close follow-up of reports/activities/deliverables deadlines and responsible partners.

*	Preparation and organisation of the GA in Berlin (09-10 November 2010).

*	Preparation above Berlin GA meeting minutes.

*	General organisation of the small and large scale tests as executed in Trento.

*	Following the Quality Control Procedure for the project that was defined from the beginning of the project.

*	After the Quality Review, all project deliverables were sent to the EU within the project execution:

D1.1: Specifications for the Sensing System, the interrogation unit, the communication system and the SDPM. Sent to EC on the: 15/4/2009.

D2.1: Methodology for the Deterministic and Probabilistic Assessment of Structural Condition Under Normal Operating Loads. Sent to EC on the: 15/4/2009.

D3.1: Methodology for the Deterministic and Probabilistic Assessment of Structural Condition Under Seismic Loads. Sent to EC on the: 15/4/2009.

D4.1: Methodology for the Deterministic and Probabilistic Assessment of the Global Structural Condition. Sent to EC on the: 11/06/09

D5.1: The Expert System, the Data Base and the Knowledge Base (Prototype V1) (D5.1) - Accompanying report. Sent to EC on the: 12/11/09.

D7.1: Plan for the Use of the Foreground (Draft). Sent to EC on the: 12/11/09.

D8.1: Web-site for the Project - Accompanying report. Sent to EC on the: 1/12/09.

D5.2: The Expert System, the Data Base and the Knowledge Base v2 - sent to EC on the: 25/03/2010.

D1.2: The SDPM, the Interrogator Unit and The Wireless Transceiver Module - sent to EC on the: 30/09/10.

D1.3: Embedded Deformation Sensors Evaluated at the Structural Lab and Refined - sent to EC on the: 31/03/11.

D7.3: Brochure and Demo of the Monitoring System and the DSS (Final) - Demo CD and brochure distributed at the final workshop (18 March 2011) - snapshots and content have been included in the D7.2 deliverable.

D2.2, D3.2, D4.2: 2.2. Module 1, Evaluated at the Structural Lab and Refined, 3.2. Module 2, Evaluated at the Structural Lab and Refined, 4.2. Module 3, Evaluated at the Structural Lab and Refined - Sent to EC on the 09/05/2011.

D6.1: Report on the Whole Simulation Tests and the Calibration and Validation of the Theory of Seismic Failure. Sent to EC on the 18/05/2011.

D7.2: Plan for the Use of the Foreground (Final). Sent to EC on the 26/05/2011.

D5.3: The Integrated DSS and Package -final. Sent to EC on the 01/06/2011

D5.4: The System Guide and User Manual. Sent to EC on the 02/06/2011

Corrective actions taken/suggested:

* During the 1st year of execution, the partner OSMOS was removed from the consortium and replaced by the partner OPTRONICS.

Project Meetings:

* Kick-Off Meeting, Athens, 30-31 October 2008
* Plenary meeting, Rome, 26-27 February 2009
* Plenary meeting, Santorini, 25-26 June 2009
* Plenary meeting, Padova, 8-9 October 2009
* Plenary Meeting, Athens, 10-11 March 2010
* Plenary Meeting, Berlin, 09-10 November 2010
* Final Meeting (and workshop), Athens 17-18 March 2011

Technical meetings:

* Civil Technical Meeting, Athens, 27 January 2010
* Technical Meeting, Dresden, 27July 2010

Potential Impact:

Socio-Economic Impact:

The assessment of operating life of civil structures has recently become crucial, because in the first place it takes to a better environmental impact due to the life extension of the structure and secondly it reduces the overall costs for demolition and rehabilitation of damaged segments.

The deployment of monitoring systems based on the MONICO project, which normally allow control of the structure in a continuous way, will strongly help both to increase its working life, leading to improvements on environmental conditions and cost reductions.

MONICO will introduce also a new concept on tunnel structural maintenance. Presently the verification of structural conditions is still based on periodic visual inspection, carried out by trained experts. This procedures are usually very expensive, time consuming, due to structure complexity, subjective, because the technicians normally cannot rely on historical data on structure and finally unreliable, because it cannot detect damages that are not yet visible.

Moreover, when the degradation is getting visible, it might be that the damage has already got to a level which could require huge costs for restoring. Indirect costs are also to be considered, due to tough access to the structure, which takes to delays and inefficiency suffered by the users.

At present, the most used method to prevent tunnel damages is normally called "Corrective Maintenance". According to this procedure, the damaged tunnel section is simply replaced with new one; this takes to high cost levels, either direct or indirect, reduced safety levels and high environmental impact.

An alternative method which is becoming more and more used is called "Proactive Condition-Based Maintenance". With this approach, the monitoring system which reads the data continuously provides the potential warning conditions of structure on the first stages; as consequence there's a lower maintenance level cost, because the inspections can be carried only after a real request, an increase of safety level and a better management of structure.

The actual importance of the MONICO project will evolve in cases where it's necessary to evaluate the tunnel structural conditions after an earthquake. Normally the seismic event can cause asymmetric loads so that the structure can exceed its functional limits. If that overcoming does not take to evident signs of damage, it's necessary to carry a deep structural analysis. The problem is even more complex because there's in first place a shortage of experienced technicians to perform these analysis and secondly the need to close the structure accesses for enough time, just in those periods for which it would be necessary to have as many road links as possible.

The monitoring system based on MONICO will give on the contrary an immediate and reliable evaluation of suffered damages, allowing the operators to decide if the structure has to be shut down or not and thus aiding civilian safety, injuries or other unfortunate events that may be caused due to any earthquake aftermath.

Contribution to Standards and Policies

MONICO is a project based on using of fibre optic sensors, presently one of the most promising market segments. It is then in full accordance with EU policies which aid to adopt all the efforts to increase within EU the share of growing markets.

The high technological profile of MONICO will help to form expert technicians on fibre optic technology, following those recommendations of treaty of Amsterdam which concern social affairs and employment policies.

As we know, one of the main features of the project is the ability to monitor a structure continuously for its whole operating life; for that it will be possible to obtain both helpful details for a better standardization of ways to design a tunnel and more complete understanding of the behaviour of structure in non-linear conditions.

Within the efforts for decreasing of civil structure environmental impact, MONICO is pursuing the ETAP (Environmental Technologies Action Plan) objectives, because it allows both to reduce the operating costs and consumption of resources and makes to grow the EU role within the development of environmental technologies.

The ECTP (European Commission Transport Policy) points out as primary target the reduction of deaths on the road by at least 50%; MONICO will give its contribution by means of its new safety concepts.

Finally, other SMEs active in the optical monitoring technologies will benefit from MONICO outcomes, through the purchasing or licensing the MONICO results. This follows the EU objectives towards increasing SME competitiveness in Europe.

Dissemination of Results

- Dissemination strategy and Plans:

The goal of the dissemination strategy within the project follows a two-fold direction:

* Disseminate the scientific results of MONICO outside the project boundaries and partners

* Prepare the ground for the commercial exploitation of the project by reaching out to target groups that may be interested in the technologies produced within the project

To reach these dissemination goals the project has adopted both a dissemination plan that will not jeopardise the commercial character of the project (see in the next section) and on the other hand reach a maximum audience.

- Dissemination Manager:

The Dissemination Manager of MONICO was in charge of coordinating the task activities and monitoring the publications and project presentations to the public. The MONICO Dissemination Manager's contact details can be found below:

Dr. Bruno Griffoni

GHT Photonics Srl

via Istria 55, 35135 Padova

ITALY

E-Mail: bgriffoni@ghtphotonics.com

The responsibilities of the Dissemination Manager are as follows:

* Define, with the cooperation of the project coordinator leader, the dissemination strategy goals

* Produce the corresponding plan for the use and dissemination of the foreground, in order to achieve the dissemination goals and explain the actual use by the SMEs of the expected project results.

* Establish which information is suitable for dissemination and define how knowledge and intellectual property issues will be managed within the consortium

* Supervise the realization of the dissemination plan and provide updates when necessary;

* Coordinate the production of the dissemination material (leaflet, poster, videos, newsletter etc);

* Monitor and record the dissemination activities of the project (workshops, participation in events etc);

* Monitor the project's presentations and publications and ensure with the cooperation of the project coordinator their compliance with the principles for proper authorship, quality of content, intellectual rights, disclosure permission etc;

* Be the contact point for the dissemination task within the consortium and also for the public;

* Monitor any other activity on dissemination that may arise during the project's duration.

- Dissemination Strategy Goals and Targets:

The MONICO dissemination strategy is composed of a set of goals based on which the definition of the dissemination plan took place. Specifically the goals of the dissemination strategy are the following:

* To widely disseminate the problems to be addressed and the concept of the MONICO project.

* To increase public awareness in the very sensitive and important issues that MONICO addresses.

* To diffuse the results and achievements of the MONICO project to all interested actors.

* To push use of monitoring systems based on optical sensors for continuous control of civil structures.

Based on this and taking into account the target groups definition a dissemination plan was designed which was not static but on the contrary was updated as new opportunities for dissemination arose and new project's results were ready to be exhibited to the public.

The dissemination team was responsible for targeting the following groups:

* Companies which are active in structural monitoring area;

* Agencies which own and operate tunnel facilities;

* Companies that provide tunnel rehabilitation services;

* Companies which are already active in monitoring with optical sensors which could purchase or license the MONICO results;

* Provider of optical monitoring services which could combine the DSS or some parts of it into their technologies;

* Owners of underground facilities built with concrete like pipelines or reservoirs which can benefit of MONICO outcomes.

- Dissemination outside the Project:

The channels for spreading the project results to third parties will be described in the rest of document. At the beginning, the dissemination was carried to increase the awareness of project; afterwards, when the first results became known, the dissemination focused on their diffusion through the ways described below.

- Dissemination within the Project:

The dissemination activity within the project is also fundamental. Indeed, the raising of information from the other workpackages is crucial, as well as the keeping of information flow among all the different projects teams. Moreover, the dissemination team has assured its presence at all general meetings scheduled within the project. To facilitate the SMEs with the assimilation, dissemination and exploitation of results, the RTD performers provided training to the staff of the participating SMEs in the use of the monitoring system and the DSS.

- Dissemination Plan:

For each of the specified target groups and with the aim to achieve the Dissemination strategy goals, the dissemination plan was designed as a working document since it was regularly updated in order to include more dissemination activities as new opportunities arose for presenting the project's most recent results.

- Dissemination Channels:

The MONICO dissemination channels included the production of various types of dissemination material, the presentation of the project in scientific journals, conference proceedings etc. and the organisation of a workshop for the project presentation.

- Dissemination Material:

The dissemination activities planned for the project included the production of a set of dissemination materials that presented the project's concept and expected results. The dissemination material produced included graphical elements in a way that a project's image is conveyed to the public in the most attractable way possible. The material developed included leaflets, posters, website, newsletters and a final project brochure and demo CD. These are described in detail in Chapter 6 of deliverable D7.2 and also in the report annexes (actual material layout etc).

- Publications and Press Release:

An important part of the MONICO dissemination activities are the presentation of MONICO to various events of interest such as symposia, workshops and exhibits that focus on tunnel facilities management, structural monitoring, smart structures, fibre optics and NDE for health monitoring in construction and the scientific publications in journals, magazines or conference proceedings. These were coordinated by the dissemination manager who was responsible for ensuring their respect to the basic dissemination principles in this project. The dissemination manager also kept a record of the achieved publications.

- Workshop:

At the end of the project, a MONICO workshop was organised in Athens on the 18th of March, 2011. The goal of the workshop was to provide a state-of-the-art report on recent research activities, technological utilisation and commercialisation activities in structural monitoring systems and software for structural assessment for transportation tunnels. This event has brought together European managers of tunnels (Attico Metro and London Underground), companies in the area of structural monitoring in construction and sector experts. The workshop agenda can be seen in Annex VIII of D7.2, while the presentations can be downloaded from http://www.monico-eu.org/products6.php?page=news-workshop

- Newsletter Mailing list:

A mailing list has been implemented composed of people interested in the project's activities belonging to any of the target groups mentioned above. The members were recruited through the partner's contacts, the project's website or on site during MONICO presentations, workshops etc. The mailing list members regularly received updates on the project in the form of newsletters and were invited to participate in public project's events.

- MONICO 1st year:

During the project 1st year, the project had no actual results developed. Therefore, the focus of the dissemination task was to advertise the concept of the project and its expected results. However the dissemination material such as leaflets, posters and the website were prepared. In addition, the project presentations in major European events aimed to exhibit the concept of the project. The development of the project's website and its continuous update with news and public documents was a major task of the entire duration of the project.

- MONICO 2nd year:

Starting from the second year of the project, publications which reported the results achieved were produced (see section 6.8). All such publications formally followed an internal review process and were published after the authorization of the MONICO dissemination manager to ensure that no confidential information is released. Towards the end of the project, the MONICO workshop took place as discussed under 3.2.1.3 above.

Dissemination Procedures:

- Principles:

Since the RTD performers provided the SME participants with the full ownership and exploitation rights of all results generated by the project, the RTD performers will not have any rights on the exploitation of results and this includes scientific publications. However, it is expected that publications on project results increase their marketability. Thus, the RTD performers published the project results after these publications had the approval of the SMEs Steering Committee and provided that in no way they will decrease the potential of the developed technology to be patented. For avoiding confusion and misconceptions and for enhancing the quality of the presented material, all dissemination activities followed a number of important principles:

* Respect Intellectual Property Rights (IPR) of all partners.
* Respect the work of all partners.
* Ensure the proper reference of all relevant parties whose work is directly or indirectly mentioned in the proposed publication.
* Follow transparent procedures.
* Respect confidential results and results that commercial issues arise.
* Avoid overlapping or duplication of dissemination events.
* Clearly distinguish between results suitable for dissemination and exploitable results.
* Target the right audience.
* Always mention MONICO and the EC / IST financial support to the project.
* Always follow the procedures described within this document.

- Procedure for presentation of MONICO project in press and events:

The following were considered as dissemination events:

* Exhibition stands and demos
* Realization of project's workshops
* Press releases
* Public project presentation
* Publications in relevant Journals
* Presentations in Conferences

* Participation in non-project workshops, forums and/or events

* Production of newsletters, leaflets, posters etc.

* Special session organisation

The Project Coordinator and the Dissemination Manager were informed about the participation of any Participant in such an event through the completion of the appropriate form (from Forms A to D) from Annex I of D7.2. They were responsible for approving or not the participation in such an event, after having received comments from the SME's Steering Committee and the rest partners in the Consortium. For any scientific journal publication, the following procedure was followed as described in the annexes of D7.2:

* Completion of appropriate form (from Forms A to D) from Annex C and submission of it to the whole Consortium through E-mail.

* Written acceptance sent to the requesting Participant within 5 working days from receipt from both the Coordinator and the Dissemination Manager. Else, it is supposed to be positive.

* The draft paper was then circulated to all project participants before submission. All participants could object to the publication of confidential data or to non-inclusion of their name, if their work was also included. Comments were to be sent to the publishing Partner with copies to the Project Coordinator and the Dissemination Manager. Then the author should restructure the draft paper accordingly. In case of conflict, it was the task of the Project Coordinator and the Dissemination Manager together to take the final decision.

* After paper acceptance, the revised relevant Form from Annex C were to be sent to the Project Coordinator and the Dissemination Manager, together with a copy of the final paper.

* After the dissemination event took place, a final version of the relevant Form from Annex C were to be sent again to the Project Coordinator and the Dissemination Manager for their archives.

The participation in exhibitions through a stand and the presentation of demos of the project results also required prior agreement of the whole project Consortium. The above rules were applied and checked by the Dissemination Manager in order to:

* Avoid repetition of publication of the same work

* Avoid publication of restrictive and/or commercial in confidence data

* Avoid misunderstandings between Participants and publication of one's work without proper referencing

* Secure optimum use of dissemination resources of the project

* Guarantee proper archiving of all dissemination material

Project Exploitation

The exploitation of the project results followed the initial dissemination actions. The exploitation involved a set of incremental steps, such as:

* Identification of possible project results;

* Identification of target market areas;

* Identification of possible key actors and customers in the area;

* Investigation of marketing positioning for the MONICO technology;

* Market Analysis;

* Definition and detailed description for the exploitation of the MONICO products amongst the project SMEs.

In the paragraphs that follow we have included a description of the above actions.

- Exploitable Results:

Following below are the project's exploitable results:

* Regarding the FBG system the project exploitable results, include the selection, testing and proper configuration of Fiber Bragg Grating sensors for their installation into tunnel linings. Furthermore it includes the modifications to the AOS FBG interrogation system able to monitor seismic frequencies into tunnels.

* Concerning the BRILLOUIN system, the exploitable results include the selection of suitable fiber (telecom SMF28 fiber with 250μm coating for enhanced sensitivity); the configured Brillouin sensors and techniques for the improvement of spatial resolution by 50% through fiber coiling.

* As far as the Decision Support System (DSS) for Structural Assessment of Monitored Tunnels under operating and seismic conditions is concerned, this includes the following:

- A module on the 'Local Structural Condition under Operating Loads'
- A module on the 'Local Structural Condition under Seismic Loads'
- A module on the 'Global Structural Condition under Operating and/or Seismic Loads'
- User Interface
- Interfaces to the (tunnel) company specific data bases
- Interfaces to all three modules above

The fiber optic sensors (either based on Bragg gratings or Brillouin time-domain-reflectrometry) are placed on the inner and outer side of the cross section of a reinforced concrete tunnel lining to report strains at eight cross sections where the maximum moments are expected to develop.

Under operating loads strain measurements from the 16 points (two in each monitored cross-section) are reported in predetermined times, say, once every 4 months, or on demand. Under seismic loads 20 strain measurements are reported per second. The above measurements provide input to the various modules of the DSS that is using it to assess the structural condition of the tunnel lining in the 8 monitored locations (Local Structural Condition) or the structural condition of the overall monitored cross section (Global Structural Condition).

More specifically:

The module on 'Local Structural Condition under Operating Loads' converts measured deformations to strains, curvatures, deflections, stresses, bending moments and axial forces which are being monitored so that they do not exceed limit values. It can, thus, assess the structural condition and structural adequacy, of the 8 monitored cross-sections at the time of the measurements.

The damage done to a cross-section during strong motion excitation depends primarily on the energy transmitted and dissipated by the cross-section during inelastic cycling. In the module on 'Local Structural Condition under Seismic Loads' the measured deformation time history during an earthquake is used for the construction of the whole history of hysteresis loops during the earthquake based on which the dissipated internal flexural bound energy is calculated. This is subtracted from the initially available such energy to determine the remaining capacity of the lining section to dissipate energy and the degree of damage in the 8 monitored locations, immediately after the earthquake.

The above provide an assessment of the local structural condition at the points of the tunnel cross-section that are being monitored. They do not provide, though, an estimate of the global stability of the monitored cross-section, nor do they provide an estimate of the external loading - earth pressure from the surrounding soil - on the tunnel lining which varies as a function of time as the temporary lining becomes less and less active.

Under operating loads the bending moments, axial forces and the corresponding curvatures and axial strains are determined at the eight monitored points as discussed above. However, the global condition assessment requires the above values to be estimated for the totality of the points along the perimeter and in addition to assess the values of the shear forces and the relative radial displacements (convergences) of the tunnel lining.

The traditional procedure for the estimation of the above values (that constitute the actual global condition of the structure) consists of the analysis of a finite element model of the tunnel cross section subjected to applied external loads, distributed continuously along the perimeter. Yet, the values of these loads are not available.

The problem of estimation of the loads acting on the lining has been solved in the Module on Global Structural Condition under Operating and/or Seismic Loads by applying a back analysis procedure. The known 16 values of the bending moments and axial forces at the 8 points of the tunnel cross section where strain sensors are installed are introduced as initial data. From these data and through back analyses it is possible to estimate 16 parameters defining the distribution of the radial continuous loading acting on the tunnel perimeter.

Under seismic loads hinges are formed at the location of maximum bending moments under elastoplastic behavior of materials. The degree of damage of these hinges is estimated in the module on Local Structural Condition under Seismic Loads as described above. In the module of Global Structural Condition under Operating and/or Seismic Loads the rotation capacity of each hinge is considered to be approximately proportional to the value of this degree of damage. Then, global instability, (considered as equivalent to a total failure of the tunnel lining) results when, after the formation of a number of hinges, a kinematical mechanism is created permitting finite, instead of infinitesimal, displacements.

The architecture of the Decision-Support-System (DSS) in project MONICO can be seen in D7.2. It includes a data base (DB) that stores all relevant information, data (structural element information and sensor measurements), rules, cases and relationships, an expert system that acts as an intelligent intermediary between the user and results that can be obtained by the system and the calculation modules that can assess the structural condition of the tunnel.

Through the integrated DSS and monitoring system the user is able to estimate the present structural condition at the 8 monitored sections in the tunnel cross-section as well as the overall structural condition of the cross-section. Moreover, the user is able to examine the external loads at the tunnel perimeter, the history of strains during an earthquake, and what is the structural condition of the monitored sections and the whole cross-section after an earthquake. The DSS provides real-time alerts and warnings in case of abnormal situations and allows the end-user to examine different scenarios for hypothetical situations.

All structural modules provide deterministic assessments of the structural condition (factors of safety) as well as probabilistic assessments of the structural safety (probability of failure). The scope of this work is limited to reinforced concrete (r.c.) tunnel primary linings. Moreover, since fiber optic sensors are required in the inner (as well as the outer) section of the tunnel lining, the developed package is of interest for new tunnel construction.

AOS, GHT and OPTRONICS intend to make an effort to expand the system to include existing tunnels as well as tunnels with segmented linings. To pursue this goal MONICO results were incorporated in a research proposal with the acronym TRANSIT (FP7-NMP-2011-LARGE-5, Proposal No 280799-1). Unfortunately this proposal was not successful yet.

- Target Groups:

The primary target group of MONICO is agencies which own or manage tunnel facilities.

There is an increasing awareness of the sensitivity of tunnels to seismic activity. Moreover, the damage to the tunnel structure is difficult to assess and a damaged tunnel that has survived the major earthquake might not have the capacity to survive consecutive seismic aftershocks. Such aftershocks take place within few hours of the earthquake and have been reported to have an intensity of up to 90% of the earthquake intensity.

In the aftermath of a damaging earthquake, transportation officers must make critical decisions regarding shutdown of damaged tunnels. Without a rapid damage detection and assessment tool that would advise whether the tunnel can remain open or should be shut down, transportation officers have to be conservative and call for an automatic shutdown of tunnels that are suspect of being damaged. Although prudent from the standpoint of not exposing lives to the direct risk of tunnel collapse, this action may lead to more serious ramifications including no passage of emergency vehicles (ambulances, fire engines, trucks, etc.). Accordingly, information on the tunnel seismic damage, structural adequacy and capacity to withstand possible aftershocks is invaluable to tunnel owners and managers in earthquake prone countries.

Furthermore, the information on the evolution of external forces is invaluable for tunnel owners and managers as well as researchers that do not know how external loads on the lining vary as a function of time and what is their effect on global stability of the cross section.

Additional target groups for MONICO are:

* Companies which deploy monitoring systems;
* Tunnel rehabilitation contractors;
* Public centers which regulate standardization reference;
* Tunnel designers;
* Providers of fibre optic sensing services;
* Representatives of relevant associations as following:

  - Optical Industry Development Association;
  - International Tunnel Association;
  - Construction Management Association;
  - International Tunneling Insurance Group;
  - World Road Association and so on.

- Data Base of Potential Customers:

Early in the project a list of major potential customers in Greece, Italy and Germany has been established (see Tables in D7.2). At the beginning the partners sent to all of these potential customers a preliminary e-mail with a presentation of MONICO; later, however, they kept them posted with regular e-mails, whenever the website was updated with new documents.

Further to the above an extensive market analysis has been included in the deliverable D7.2, including sensing interrogation technologies and detector types but also potential MONICO competitors. Also in the same report, an estimate of the potential market for the MONICO results in Greece and Italy has been included. The exploitation of results per partner can also be found in D7.2. The SME partners have signed the exploitation agreement that can be seen in Deliverable D7.2, Annex VII. Moreover, they have decided that market launch in the first instance will take place in Greece and Italy, the countries with the highest seismicity in EU. Additionally, they have decided that critical, in order to successfully sell the MONICO results, is to have some pilot studies. To this end they have contacted the management of Attico Metro that is extending its network and the management of TRENOSE that is currently building one of the largest railway tunnels in Greece.

Dissemination Material and Achievements:

The produced dissemination material is presented below and can be found in detail in the deliverable D7.2.

* LOGO - designed in a way to reflect the fundamental technology used in MONICO.

* Website - designed using the same graphical elements as in all dissemination materials. Frequently updated throughout the project

* Newsletters - issuing and disseminating regular electronic newsletters which include latest news on the project, achievements, announcements etc.

* Flyer and Poster - production of a colour flyer and poster which was handed out at conferences, workshops as well as important related events.

* MONICO Brochure - developed under D7.3 (M30) of the project

* MONICO Video - production of a video including the innovation of the MONICO project in terms of technologies and actual results.

* MONICO Demo-CD - including Latest newsletters, Project Leaflet, Project Brochure, and MONICO video.

* Workshops, Conference and Trade Shows: Dissemination was carried also through attending to workshops, conferences and trade fairs.

List of Websites:

http://www.monico-eu.org