SIBYL

(Se**I**smic monitoring and vulnera**B**ilit**Y** framework for civi**L** protection)

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Deliverable DA3: Second Progress Report

(Covering period 01.09.2015 to 30.04.2016)

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General reminder

Cost-efficient and reliable methods to assess an area's seismic (or any other hazard) vulnerability in order to undertake risk estimation and response planning are an essential requirement for Civil Protection (CP) authorities. These methods would also be needed in the occurrence of seismic swarms or foreshocks, where a prompt assessment of the threatened area would be necessary. In both cases, such actions would be especially important for regions that lack reliable and up-to-date building stock information. As part of efforts to confront such issues, the SeIsmic monitoring and vulneraBilitY framework for civiL protection or SIBYL project is setting out to develop an operational framework for CP authorities to allow them to undertake rapid and cost-effective appraisals of the seismic vulnerability of the built environment, and to efficiently use the acquired information to optimize disaster mitigation management and emergency response actions. This framework will advise decision makers as to the most appropriate preventative actions to take, when is there a need for short-notice vulnerability assessments in a pre-event situation, as well as monitoring the built environment's dynamic vulnerability during a seismic sequence and undertaking vulnerability assessments as part of a longer-term risk management strategy. The framework (which includes software and hardware tools) will have the flexibility to be applicable to multiple spatial scales, while its modular structure will allow its adaptation to other natural hazard types. The demonstration of the developed methods to CP personal will serve as a training component, while setting the stage for the framework´s integration into operational protocols. This will enhance CP operational capacities at the pre- and post-event stages, while ensuring the legacy of the SIBYL results.

The SIBYL consortium is coordinated by the Centre for Early Warning Systems of the Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences (GFZ). GFZ has extensive experience in seismic hazard and risk assessment, including the development of low-cost monitoring and exposure and vulnerability data gathering systems. The other members of the consortium are AMRA S.c.a.r.l., (AMRA, Naples, Italy), a Centre of Competence in the area of analysis and monitoring of environmental risk, the Geotechnical Engineering Division of the Aristotle University Thessaloniki (AUTH, Thessaloniki, Greece), and the Chair of Structural Mechanics, Technical University – Berlin (TU-BERLIN, Berlin, Germany).

The expected outcomes and deliverables of SIBYL are as follows:

- The production of guidelines for CP authorities for implementing the developed framework for optimizing mitigation actions at various spatial scales and stages of a seismic crisis. The guidelines will cover the use of a mobile mapping system and the remote analysis of the acquired imagery, methodologies for the analysis of spaceborne remote-sensing images, structural appraisal and short-term monitoring procedures (including instrumentation), site-effects surveys and assessing time-variant seismic risk.
- Software tools that are exploitable by CP practitioners with the minimum amount of training for acquiring and analysing different observations that cover various spatial scales with the capacity to identify a structure's dynamic seismic behaviour while considering other factors such as site effects.
- Training and capacity building for CP practitioners with regards to the optimal exploitation of the framework, including cost-benefit analyses.
- Outreach activities to interested parties on the aims and results of the project.

General summary of the project's implementation process

During the first period (01.01.2015 to 3.08.2015), most activities were concerned with the preparation of the technical activities, in particular the planning of field work and the compilation of the available information about the buildings that will be the test cases for monitoring and analysis. During the second period, field work was carried out in Thessaloniki and Cologne, these activities reported upon in two reports sent to the EC-ECHO science officer. This involved further testing of the real-time software tools developed during this period. In addition, the analysis techniques that will form part of the framework for the temporal evolution of a structure's vulnerability underwent development.

The first payment was received and distributed to the consortium during the first period. One comment made on the financial reporting for the first period was that there appeared to be less spending than expected. This was due to the planned travel and field activities not yet being undertaken, and the requirement to find appropriate staff. The second period, as outlined in this report, saw increased expenditure, with the required/planned resources still within the limits set out in the original proposal.

Evaluation of the project management/implementation process

The management of the project is proceeding adequately, with no major difficulties arising. Communication within the consortium has been effective in terms of the planning of the field activities and the distribution of required information. The main event was the mid-term meeting held in Thessaloniki, where members of the Greek CP also attended. Communication with EC-ECHO has mainly been in the form of 'unofficial' reports dealing with the field work and mid-term meeting.

In summary, the consortium is confident that the project will successfully complete its aims by the end of the project (31.12.2016). All deliverables due by the end of the 2nd period have been completed. Some modifications to the project's plan have been made involving travel and dissemination activities. These changes were presented to and approved by the EC-ECHO science officer.

Activities

- The mid-term meeting of the project was held in Thessaloniki (15-16 February, 2016).
- Field activities involving structural monitoring and measurements and site assessment were carried out in Thessaloniki (September-October, 2015) and Cologne (November-December, 2015). Associated with these activities were demonstrations to local CP representatives.
- Real-time software has been developed and tested for use with the MP-Wise sensor units which is able to carry out preliminary site assessments (e.g., V_{s30}) and structural characterisation.
- Development of a structural reliability assessment model based on a Markov-chain-based approach, which is able to account for changes that arise in a structure's seismic response due to damage.
- Development of in-situ data collection procedures for structural modelling and building assessment.
- Development of structural reliability assessment models, which are able to account for the evolution of structural damage during seismic sequences.

Presentation and evaluation of technical results and deliverables

Task B “Rapid data collection and integration”

A software package (a plugin for the QGIS - Quantum GIS - geo-information platform) for processing medium-resolution satellite imagery has been developed. The package allows the streamlining of the analysis of extensive areas subjected to complex urbanization processes, and to provide a preliminary and rapid characterization of land-cover and land-use. This information will then be used to optimize in-situ exposure surveys (e.g., residential building stock). Moreover, a web-based platform called RRVS (Remote Rapid Visual Survey) has been incorporated to complement the tools and methodologies related to optimizing the surveys and the deployment of a mobile mapping system for the rapid mapping of the built environment.
The required deliverables for this task have been completed and delivered, namely DB1: Guidelines for the remote-sensing assessment methodology, DB2: Software platform including processing tools with related manual, and DB3: Guidelines of the mobile mapping system and remote rapid visual screening.

Task C “Rapid and low cost in-situ building vulnerability assessment”

Two measurement campaigns within this task were carried out (AUTH, GFZ, TU-BERLIN): (1) in September-October 2015, two buildings of AUTH were investigated and (2) in November-December 2015 seven school buildings located in the city of Cologne. The data and information gained from monitoring these buildings were analysed to evaluate the buildings’ dynamic behaviour and are being used as input to the predictive modelling tools under development to determine their seismic response and vulnerability. Reports on these field activities were sent to the EC-ECHO project officer.
For the AUTH buildings, several approaches were followed for the modelling: the simplified structural model approach (TU-BERLIN) and the use of refined 3D finite element models (AUTH). Modal analyses of the numerical models of these buildings have been performed and the numerically extracted modes and mode shapes have been compared with the experimentally computed ones which have been extracted through operational modal analysis using the monitoring data and information. Finite element updating of the numerical models has been performed in to represent the measured response. For the nonlinear updated model of the Administration building, incremental dynamic analysis has been conducted and the same method will be used for the Faculty of Philosophy building as soon as the nonlinear numerical modelling of the structure has been finalized. The seismic records used for the dynamic analyses were selected based on the regional hazard and the results will be used to derive the fragility curves for the two test structures.
For the Cologne field work, the investigated buildings are of different structural systems, sizes and geometry, years of construction and state of maintenance. Special software was developed in TU-Berlin for rapid data collection during in-situ inspections and creating databases for immediate use for the modelling and structural analysis of the buildings under consideration. Moreover, a simplified (EXCEL-based) procedure has been developed for the pre-processing and analysis of the collected information.
A procedure for simplified structural analysis and vulnerability assessment is currently under development. First, it includes simplified structural modelling based on limited information on the structure collected directly on site in a short (few hours) time, including the buildings’ dimensions, structural and material type, dimensions of the main structural members and their position, as well as data from on-site non-destructive and vibration tests. The simplified integral structural model assumes one beam element with two degrees-of-freedom per floor (two orthogonal horizontal displacements) with integral floor stiffness, taking into account

the main structural members (columns, beams, walls and a slab). The model's development is completed and its validation (and improvement) is being done using the calculated and measured natural frequencies and corresponding mode shapes of the buildings. In the second step, the model is being extended to include the nonlinear behaviour and limit states of the structure within the framework of damage and plasticity theory for reinforced concrete. The third step will see the nonlinear model serving as a core tool for quasi-static simulations within the stochastic pushover analysis. The latter will allow the construction of fragility curves.

In addition to the structural monitoring, ambient noise measurements were performed in both test sites to assess soil conditions and site effects characteristics in terms of resonant frequency, amplification factor and shear wave velocities with depth. This involved 2D array measurements using CUBE digitizers connected to 4.5 Hz geophones. Using real-time software developed by GFZ, the phase velocity dispersion curve of Rayleigh waves and the V_s profile of the soil were found via the Spatial Autocorrelation Coefficient (SPAC) method, and the Horizontal to Vertical Spectral Ratio (HVSR) method to determine the resonant frequency of the soil and to get an idea about the amplification factor.

Task D "Real-time monitoring during a seismic sequence"

A closed-form model approximating the structural reliability problem during a seismic sequence has been developed[1]. The model is based on age-dependent stochastic processes, and refers to non-evolutionary elastic-perfectly-plastic single degree of freedom (SDoF) systems. The model is able to account for different levels of knowledge about the structural damage state and can be coupled with information acquired by the sensing system being developed within the project. However, because it refers to a non-evolutionary SDoF system, some simplifications have to be accepted. The importance of these simplifications is dependent on the structural characteristics of the monitored building. For example, in the case of masonry buildings, the non-evolutionary hypothesis may appear too strong, while it may be acceptable for steel structures.

To overcome some of these approximations, AMRA has developed a new analytical model for structural reliability assessment where the assumption of non-evolutionary behaviour is removed. The model is based on a Markov-chain approach, which is able to account for changes in the seismic response of damaged structures (i.e., state-dependent seismic fragility) as well as uncertainties in the characteristics (location, magnitude) of earthquakes (i.e., seismic hazard, both future and when one has occurred)[2]. This model is able to account for: (i) homogeneous rates of earthquake occurrence (the accepted hypothesis when main shocks are of concern), (ii) time-variant rates of earthquake occurrence (aftershock sequence), (iii) seismic behaviour of the structure changing over the time because of, for example, aging, and (iv) other types of shocks different from earthquakes (e.g., fatigue). Moreover, information acquired from the sensing system can also be utilized in this model.

A multi-parameter monitoring system that allows several kinds of sensors to be combined with a high performance computing system able to implement complex information integration and processing tasks at the node (sensor) level, and therefore be suitable for a wide range of possible applications, i.e., structural health monitoring, on-site and regional earthquake early warning and other uses, has been developed and is being tested, along with the associated software. The sensors that may be considered include: standard strong motion and weak motion sensors, broadband seismometers, MEMS sensors including accelerometers and gyroscopes, cameras, temperature and humidity sensors and a low cost GNSS system. The concept of

[1] Iervolino I., Giorgio, M., Chioccarelli, E. (2014) Closed-form aftershock reliability of damage-cumulating elastic-perfectly-plastic systems. *Earthquake Engineering and Structural Dynamics*, vol. 43, pp. 613–625.

[2] Iervolino I., Giorgio M., Chioccarelli E. (2016) Markovian modeling of seismic damage accumulation. Earthquake Engineering and Structural Dynamics. 45(3):441–461.

the system is to shift part of the processing burden from a centralized location to a set of sparse, interconnected or even single computing nodes. In this context, the analytical reliability model developed in Task D will be implemented in the multi-parameter monitoring system.

Task E “Training and capacity building”

A workshop demonstrating the SIBYL tools and methodologies was prepared for during this period, and took part from 30th to 31st May, 2016, in L’Aquila, Italy. It will be reported on in deliverable DF4: Report on technical and professional outreach.

Task F “Task publicity”

A dissemination activities plan was produced (deliverable DF2: Detailed plan for project publicity), although some modifications are expected to arise. The project website has been continuously updated, including providing the reports on the field work and mid-term meeting, and the associated presentations. A project brochure was completed during this period and will be made available on the website (with versions in English, Italian, German and Greek). The results of the project have been presented in several scientific workshops and conferences, with a number of papers being submitted (or in preparation) to peer-reviewed journals. During field activities in Cologne, a representative of the German CP (THW - Technische Hilfswerk) inspected the activities and was shown the various software tools and monitoring procedures. Similarly, the Greek CP authorities have been informed about the project’s progress and are actively contributing via the provision of feedback regarding the tools and methods that will be provided within the framework of SIBYL.

Follow-up

In the last period of the project, the following activities will be undertaken:

- The RRVS platform for completing the exposure database will be augmented by a software component that provides a set of analytics related to data collection, and an area-based probabilistic model of exposure, based on the collected information and - if available - a set of prior distributions (GFZ).
- Moreover, the feasibility of an additional module for post-event reconnaissance field missions (for rapid data collection related to structural and non-structural damage distribution) will be explored (GFZ).
- Derivation of fragility curves for the Administration and the Faculty of Philosophy building (AUTH).
- Upgrading the simplified integral structural model (SISM) with nonlinear material behavior for structural fragility analysis (TUB).
- If an equivalent SDoF system of a building that was monitored during the workshop in L’Aquila is developed by TU-Berlin within acceptable time constraints, the analytical reliability model developed in Task D will be fitted on the actual building (AMRA).
- The analytical reliability model developed in Task D by AMRA will be implemented into the multi-parameter monitoring system and tested under real-time conditions (GFZ).

ANNEX – UPDATED FORMS T1 and T2

Although some changes in the travel plans and outreach activities (and associated expenses) were made and communicated to the EC-ECHO project officer, it is believed that no modifications to FORM T1 is necessary.

Note in FORM T2 the highlighted deliverables have been completed or are in place (e.g., the website), including this report. All deliverables that are meant to have been completed by this time have been and have been provided to EC-ECHO.

Form T1

SUMMARY OF THE PROJECT

Objectives of the project.
SIBYL's aim is to develop an operational framework for Civil Protection (CP) authorities to rapidly and cost-effectively assess the seismic vulnerability of the built environment. The framework will provide information to advise decision makers as to the most appropriate preventative actions. It will cover cases where there is a need for short-notice vulnerability assessment in a pre-event situation, and the monitoring of the built environment's dynamic vulnerability during a seismic sequence. The framework will be flexible enough to be employed over multiple spatial scales, and its modular structure will ease its applicability to other natural hazard types. Training of CP personal in the developed methods will see the framework integrated into their operational protocols.

Why is this project necessary?
The occurrence of seismic swarms or foreshocks demands CP authorities to rapidly assess the threatened area's vulnerability. This is especially the case for regions where there is a dearth of up-to-date and reliable information. Such deficiencies result from, for example, no previous knowledge of the area's seismicity and inadequately documented urban development. As the crisis unfolds (i.e., the occurrence of a main shock), there is moreover a need for real-time information, that will allow CP responders to adopt their actions to the evolving situation. Such a situation, which may well involve cross-border areas, is an example of what the Community Mechanism for Civil Protection must deal with.
The actions called upon for CP will include the dynamic tagging of those structures that have, or may become, unsafe. Such actions will, for example, advise the population as to their movement back to their residences, or in helping to plan emergency accommodation. There is therefore the need for a rapid, cost-effective and flexible framework within which such information may be acquired. Furthermore, such a framework must be readily useable by CP operators, especially considering the frequent disconnection between the research/development and practitioner groups in hazard and risk assessment.

Describe the problem the proposal is supposed to address, background and what has been done already.
Unfortunately, most state-of-the-art approaches that can provide such information are costly and expertise intensive, hence limiting their large scale applicability and thus their capacity to contribute to efficient prevention actions. The consortium will therefore call upon experience gained from other EC supported projects to develop a practical framework for use by CP. The SAFER and REAKT projects have contributed to the development of new low-cost seismic instrumentation, suitable for rapid deployment, as would be required in an evolving crisis. Likewise within these and the MATRIX project, developments in understanding and modelling temporal changes in vulnerability due to repeated seismic events have been made, all of which can build upon the work on structural vulnerability undertaken in SYNER-G. Another source of information involves exploiting remote sensing, making use of the tools and methodologies developed within the SENSUM project.

Actions and means involved

- Selection of suitable test sites for the refinement of the field-based methodologies and training.
- Based on the analysis of remote sensing observations and knowledge of previously identified critical infrastructure, undertake in situ mobile mapping surveys, building inspections and characterisations, and the instrumentation of a selected subset of the inspected buildings.
- Further development of the required software for the integration and interpretation of the different types of data being acquired.
- During all these activities, interaction with CP participants will ensure the relevance of the developed tools to their needs, while also contributing to the required training and capacity building activities.

Expected results

- Guidelines for CP authorities on how to implement the developed framework to optimize prevention actions at various spatial scales and stages of the seismic crisis.
- Easy to use software tools exploitable by CP practitioners for the acquisition and analysis of different types of observations covering various spatial scales, their integration to identify a structure's dynamic seismic behaviour, and the consideration of other factors such as site effects.
- Training for CP practitioners on the optimal exploitation of the framework, including cost-benefit analyses.

Form T2

Project Acronym	SIBYL				
Task ID	**Task Title**	**Start Date**	**End Date**	**Actions**	**Deliverables**
A	Task management and reporting to the commission.	01.01.2015	31.12.2016	A.1 Technical coordination and communication (GFZ). A.2 Technical reporting (GFZ). A.3 Financial reporting (GFZ).	DA1: Kick-off-meeting report. DA2: First progress report. DA3: Second progress report. DA4: Final technical and financial report.
B	Rapid data collection and integration.	01.01.2015	31.12.2016	B.1 Preliminary field characterization by remote-sensing (GFZ). B.2 Rapid pre/post event assessment via mobile-mapping (GFZ). B.3 Evolutionary exposure/vulnerability model (GFZ).	DB1: Guidelines for the remote-sensing assessment methodology. DB2: Software platform including processing tools with related manual. DB3: Guidelines of the mobile mapping system and remote rapid visual screening.

Project Acronym	SIBYL

C	Rapid and low cost in-situ building vulnerability assessment	01.01.2015	31.12.2016	C.1 Simplified integral structural model approach to seismic vulnerability assessment (TU-BERLIN). C.2 Short-term structural monitoring and modal analysis of buildings (AUTH). C.3 Site-effects assessment (AUTH).	DC1: Guidelines for the building assessment procedure and short-term monitoring. DC2: Guidelines for undertaking site-effect surveys. DC3: Documentation for the developed software tools. DC4: Reports on the case studies.
D	Real-time monitoring during a seismic sequence	01.01.2015	31.12.2016	D.1 Installation of low-cost sensing units for building-specific monitoring. (AMRA)	DD1: Guidelines for the assessment of time-variant seismic risk of monitored single structures.
E	Training and capacity building	01.01.2015	31.12.2016	E.1 Training and capacity building of Civil Protection representatives (GFZ). E.2 Investigation of the transfer of the system to other hazard types (GFZ).	DE1: Training materials for the use of the developed framework and tools. DE2: Report on the potential for the developed system to be transferred to other hazard types.
F	Task publicity	01.01.2015	31.12.2016	F.1 Project website (GFZ). F.2 Multi-media dissemination material (TU-BERLIN). F.3 Public outreach and events (GFZ). F.4 Technical and professional dissemination (AUTH).	DF1: Project website. DF2: Detailed plan for project publicity. DF3: Report on public outreach events/activities. DF4: Report on technical and professional outreach.