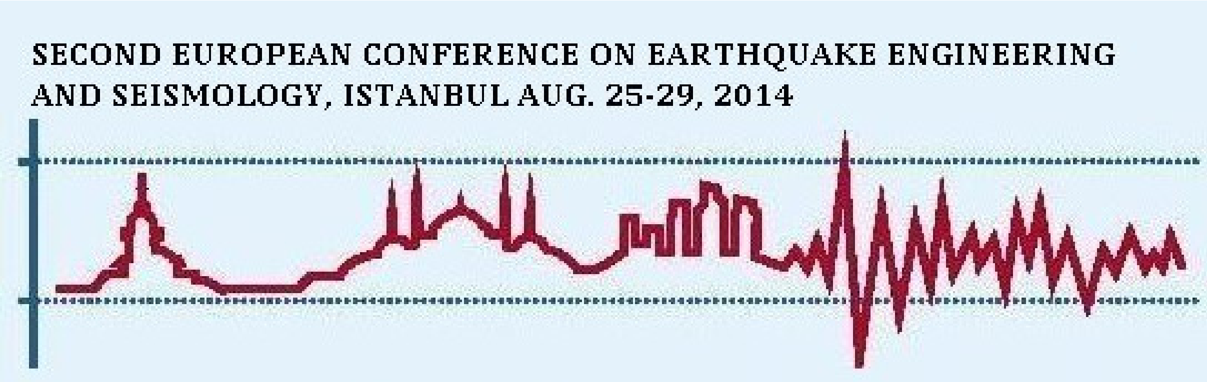

INDES-MUSA PROJECT - INTEGRATED MONITORING OF SUBSIDING COASTAL AREAS PRONE TO LARGE EARTHQUAKES: THE CASE OF KALOCHORI IN GREECE

Emmanouil ROVITHIS[1], Betty CHARALAMPOPOULOU[5], Athanassios GANAS[7], Alexandros SAVVAIDIS[2], Konstantia MAKRA[2], Kiriaki KONSTANTINIDOU[4], Emmanouil KIRTAS[8], Christos KARAKOSTAS[3], Vasilios LEKIDIS[3], Dimitris PITILAKIS[9], Constantinos LOUPASAKIS[10], Christina Tsimi[11] and Charalambos MANESIS[6]

INTRODUCTION

Seismic risk assessment of urban areas constitutes an inherently spatial problem leading therefore to an emerging need for urban-scale and highly-accurate monitoring schemes and recordings at the disposal of end-users and decision-making authorities for risk management, disaster preparedness and future urban planning. The above necessity becomes particularly meaningful in the case of complex urban landscapes including different typologies of residential structures, critical facilities and civil infrastructures. In this context, a well-focused accelerometric network has been recently deployed in the broader urban site of Kalochori located close to Thessaloniki in Northern Greece as part of the ongoing INDES-MUSA project (www.indes-musa.gr) that is funded by the Greek General Secretariat of Research and Technology (GSRT) under the framework of the Operational Programme "Competitiveness and Entrepreneurship" (OPCE II), Greece-China Bilateral R&D Cooperation. Part of the accelerometric network was installed adjacent to GNSS reference stations offering retrieval of seismic displacements from collocated accelerometric-GNSS stations in case of a strong earthquake event. The integrated monitoring scheme of INDES-MUSA project includes also a local GPS network, a tide gauge station, water level stations and airborne Lidar campaigns. A brief overview of the monitoring network focused on accelerometric and permanent GNSS stations is presented by describing the general design concept, setting criteria and salient features of the installations.

NETWORK DESIGN AND IMPLEMENTATION

In most cases contamination of earthquake recordings by structural response or soil-structure interaction of the built environment is unavoidable, especially in dense urban sites. In this regard it is critical to record ground motions that represent the actual ground shaking experienced by structures as

---

[1]Researcher, Institute of Engineering Seismology and Earthquake Engineering EPPO-ITSAK, Thessaloniki, rovithis@itsak.gr,
[2]Senior Researcher, Institute of Engineering Seismology and Earthquake Engineering EPPO-ITSAK, Thessaloniki, alekos@itsak.gr, makra@itsak.gr
[3]Research Director, Institute of Engineering Seismology and Earthquake Engineering EPPO-ITSAK, Thessaloniki, christos@itsak.gr, lekidis@itsak.gr
[4]IT Computer Science, Institute of Engineering Seismology and Earthquake Engineering EPPO-ITSAK, Thessaloniki, kiriaki@itsak.gr
[5]Geologist, Geosystems Hellas, Athens, b.charalampopoulou@geosystems-hellas.gr
[6] Electrical Engineer & Computer Technology (MSc) Expert, Geosystems Hellas, Athens, ch.manesis@geosystems-hellas.gr
[7]Research Director, National Observatory of Athens, Institute of Geodynamics, Athens, aganas@noa.gr
[8]Ass. Professor, Technological Educational Institute of Central Macedonia, Serres, kirtas@teiser.gr
[9]Ass.Professor, Aristotle University of Thessaloniki, Thessaloniki, dpitilak@civil.auth.gr
[10]Ass. Professor, National Technical University of Athens, Athens, cloupasakis@metal.ntua.gr
[11] Research Associate, National Observatory of Athens, Athens, christinant@gmail.com

Figure 1. Subdivision of the investigated Kalochori area into three urban sub-zones [i.e. industrial area (red dots), residential zone (yellow dots) and oil tanks zone (green dots)] and locations of the corresponding accelerometric and GNSS base stations.

part of an urban landscape. Reversely, the deployment of a dense accelerometric network within an urban site contributes to a large-scale assessment of seismic response of structures as affected by soil-structure interaction, thus effectively expanding the investigation from that of a single building - as is usually adopted in current design or analysis practice - to the level of urban environment (Chen et al. 2010, Taborda and Bielak 2011). Furthermore, independent measurements of seismic displacements from collocated GNSS stations allow correlation of accelerometric and GPS data within investigation of seismic motion especially for near-field effects and long-period pulses (Emore et al. 2007).

The above topics form the main design axes of the collocated accelerometric and GNSS network that was deployed very recently within the framework of the on-going INDES-MUSA project (www.indes-musa.gr) dealing with monitoring of ground subsidence (e.g. Psimoulis et al. 2007) and seismic motion in the broader area of Kalochori, west of Thessaloniki.

The investigated area shown in Figure 1 is characterized by a complex urban environment including residential building stocks, important civil infrastructures such as industries, oil tanks, power supply installations and lifeline networks. Three urban sub-zones were geographically defined referring to the residential buildings zone, the industrial zone and the oil tanks zone, allowing treatment of each sub-area as a homogenized urban unit having similar structural types and urban densities. Geological conditions at the examined site are characterized by quaternary deposits of 150m to 400m depth. A pair of 24bit accelerometric stations was installed in each sub-zone corresponding to a "*structural station"* (denoted with *S*) and an "*urban reference station*" (denoted with *UF*) respectively, following the definitions given in COSMOS, 2001. The former refers to an accelerometric station installed at the top of a representative structure of each sub-zone, whereas the latter refers to a ground installation (either on open ground or in a small structure) within each sub-zone where minor contamination of earthquake recordings by the dynamic response of adjacent structures is anticipated. More specifically, KLH1 station was installed at the R/C roof slab of the municipal gymnasium building representing a typical industrial type structure within the industrial zone of Kalochori. The second accelerometric station (KLH2) was installed in a small warehouse located next to the gymnasium corresponding to the *UF* station for the particular zone. KLH3 accelerometric station (*S* type) was installed on the geometrical centre of the roof slab of the Cultural Centre of Kalochori; a two-storey stone masonry building located in the centre of the residential zone, whereas KLH4

Table 1. Main features of INDES-MUSA collocated accelerometric-GNSS network

Accelerometric station	Sub-area of investigation	Type of station*	Description of installation	Collocated with GNSS sensor
KLH1	Industrial	*S*	RC building of industrial type	yes (KAL2)
KLH2	Industrial	*UF*	Small warehouse	
KLH3	Residential	*S*	2storey stiff stone masonry structure	yes (KAL1)
KLH4	Residential	*UF*	Small warehouse	
KLH5	Oil tanks	*S*	Steel water tank	
KLH6	Oil tanks	*UF*	Open ground	
KLH7	Free field	*FF*	Open ground	

**S*: Structural station *UF*: Urban reference station *FF*: Free-field station

station was installed at a nearby single-storey warehouse representing the second *UF* station of the INDES-MUSA accelerometric network. With reference to the oil tanks zone, KLH5 station (*S* type) was installed at the top of a steel water tank of EL.PE company through a steel base welded at the center of the tank roof. The *UF* type of accelerometric station for the oil tanks zone (KLH6 station) was installed on open ground nearby, at a certain distance from the tank's base to minimize possible interference between soil and structural motion in case of an earthquake event. Representative photos of the above installations are shown within Figure 1. Another accelerometric station (KLH7 in Figure 1) was installed on the ground surface at the opposite side of Kalochori bay representing a free-field reference station (*FF* type) away from the build environment. A set of main features of the INDES-MUSA accelerometric network, comprising seven stations in total, are summarized in Table 1. All the stations were oriented along the N-S direction and configured to operate on a continuous recording basis with real-time data transfer to the central data acquisition INDES-MUSA server installed in EPPO-ITSAK premises in Thessaloniki.
Two accelerometric stations (i.e. KLH1 and KLH3) are installed next to GNSS reference stations forming two available collocated accelerometric-GNSS stations of the INDES-MUSA project. GPS observations are archived at 1Hz on a daily basis allowing for derivation of time-series positions and velocities and for RTK applications.

ACKNOWLEDGEMENTS

The INDES-MUSA project is funded by the General Secretariat for Research and Technology (GSRT) and it is implemented under the framework of the Operational Programme "Competitiveness and Entrepreneurship" (OPCE II), Greece - China Bilateral R&TD Cooperation. Installation and maintanance of the accelerometric stations was performed in collaboration with the technical staff of EPPO-ITSAK, Apostolos Marinos and Nikolaos Adam as members of the project team. Special thanks should also be attributed to the Municipality of Delta and EL.PE Oil company for providing formal permission and technical support for the deployment of the monitoring network.

REFERENCES

COSMOS (2001) "Guidelines for Installation of advanced national seismic system strong motion reference stations," Report, Pacific Earthquake Engineering Research Center, University of California, Berkeley.

Emore GL, Haase JS, Choi K, Larson K and Yamagiwa A (2007) "Recovering seismic displacements through combined use of 1-Hz GPS and strong motion accelerometers," *Bulletin of the Seismological Society of America*, 97(2): 375-378.

Psimoulis P, Ghilardi M, Fouache E & Stiros S (2007) "Subsidence and evolution of the Thessaloniki Plain, Greece, based on historical leveling and GPS data" *Engineering Geology*, 90: 55-70.

Chen at al. (2010) "Seismic performance assessment in dense urban environments: Evaluation of nonlinear building foundation system using centrifuge tests" *Proceedings of 5th International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics,* San Diego, California, 24-29 May, paper 5.49a

Taborda R and Bielak J (2011) "Large-scale earthquake simulation: Computational seismology and complex engineering systems," *Computing in Science & Engineering*, 1(1): 14-26