Acknowledgements. This work has been funded by "Fondo di Ricerca di Base 2017 Resp. Pauselli Cristina, POR FESR 2014-2020. Asse I Azione 1.3.1 – "Avviso a sostegno delle nuove PMI innovative 2016"- Projec title: "Sviluppo tecniche/protocolli innovativi nel campo dell'acquisizione dati geofisici" Resp. Geosurveys Srls,)" and "Progetto ricerca di base 2014, Resp. Lucio Di Matteo".

References

Di Matteo L., Bigotti F., Ricco R.; 2009: *Best-fit models to estimate modified proctor properties of compacted soil*, J. Geotech. Geoenvironmental Eng., **135**, 2009, 992–996.

Di Matteo L., Pauselli C., Valigi D., Ercoli M., Rossi M., Guerra G., Cambi C., Ricco R., Vinti G.; 2017: *Reliability of water content estimation by profile probe and its effect on slope stability*, Landslides, **15**(1), 1–8.

Dobriyal P., Qureshi A., Badola R., Hussain S.A.; 2012: *A review of the methods available for estimating soil moisture and its implications for water resource management*, J. Hydrol., **458–459,** 110–117.

Ercoli M., Di Matteo L., Pauselli C., Mancinelli P., Frapiccini S., Talegalli L., Cannata A.; 2018a: *Integrated GPR and laboratory water content measures of sandy soils: From laboratory to field scale*. Construction and Building Materials, **159**, 734-744.

Ercoli M., Di Matteo L. and Pauselli C.; 2018b: *Comparison of GPR and Capacitance Probe laboratory experiments in sandy soils*, 2018 17th International Conference on Ground Penetrating Radar (GPR), Rapperswil, 1-5. doi: 10.1109/ICGPR.2018.8441567.

Evett S.R., Heng L.K., Moutonnet P., Nguyen M.L. (Eds.); 2008: *Field Estimation of Soil Water Content: A Practical Guide to Methods, Instrumentation, and Sensor Technology*. IAEA-TCS-30, 1018-5518, International Atomic Energy Agency, Vienna, Austria, 39–54 (Chapter 3) Available at: <http://www-pub. iaea.org/mtcd/publications/PubDetails.asp?pubId=7801>.

Qi Z., Helmers M. J.; 2010: *The conversion of permittivity as measured by a PR2 capacitance probe into soil moisture values for Des Moines lobe soils in Iowa*, **26,** 82–92.

Reid M.E., Baum R.L., LaHusen R.G., Ellis W.L., 2008: *Capturing landslide dynamics and hydrologic triggers using near-real-time monitoring*. In: Chen et al (eds) landslides and engineered slopes. Taylor & Francis Group, London,. 179–191.

THE MALTA - GOZO TUNNEL PROJECT: ONSHORE BOREHOLE AND SURFACE SEISMIC SURVEY IN SUPPORT TO THE GEOLOGICAL MODEL BUILDING

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In the frame of the Malta and Gozo tunnel project, OGS collected several geophysical data to provide new information for a more reliable geological model along the planned tunnel trajectory (Petronio *et al.*, 2017).

The geophysical survey was planned: to identify and map the main geological and geomorphological features, to characterize the nature, thickness and spatial variability of geological formations below the seafloor, and to identify the main faults.

The stratigraphy of the Maltese islands consists of five geological formations, ranging in age from late Oligocene to late Miocene: Lower Coralline Limestone Formation, Globigerina Limestone Formation, Blue Clay Formation, Greensand Formation and Upper Coralline Limestone Formation (Galea, 2007). The rock layers in Malta are relatively flat-lying, with the exception of zones where the rock has been folded close to faults. The faults have two main orientations, with the largest faults being northwest-southeast trending, parallel to the line of islands, although these faults are only locally exposed, and a second set that are WSW-ENE trending, with generally small displacements that dominate the topography of the islands.

Multibeam echosounder, Single-channel boomer seismic reflection and multi-channel seismic reflection surveys across study area were carried out between October and December 2016.

The main geophysical product was the offshore reflection seismic sections, natively represents the underground reflectors (layers) depth position in time (two-way time). Obviously the position of the reflectors to be useful for geotechnical application should be expressed in depth. The conversion from time to depth requires velocity measurement of the sediments and rock that are present in the study area.

Surface and borehole seismic data acquisition allow to measurement on-field rock/sediment velocities. Seismic refraction is the main method to obtain velocities information from the surface. This approach is widely adopted for near-surface/medium depth investigations (i.e., portals rock characterization, low coverage tunnel sectors, etc.). In the study area, the presence of the Blue Clay formation between two more competent formations (i.e., the Upper Coralline Limestone Formation at the top and the Globigerina Limestone formation at the bottom) limits the applicability of the refraction method because the velocity inversion. To overcome this limitation borehole measurements were planned.

Seismic borehole technique consists of sending a seismic signal from a surface source down to sensors (geophone and/or hydrophone) located into a borehole. The one-way traveltime from surface to depth is obtained by picking the times of first arrival on the observed records. Repeated measurement are taken at different depth along the borehole in order reconstruct the velocity function along the borehole itself.

The borehole and surface seismic survey took place in February 2018 after the borehole drilling completion.

P- and S-wave vertical seismic profiles (VSP) were acquired in two boreholes located close the sea in the north cost of Malta (BH3 - Marfa Road, Ċirkewwa) and in the south coast of Gozo (BH6 - Zewwieqa Road, Għajnsielem). These boreholes were cased and well-grouted to ensure good seismic coupling between the downhole geophones and the surrounding rock.

P-wave VSP data were acquired by an accelerated weight drop (PWD, about 74 Kg) and hydrophone streamer (24 channels with 5 m inter-trace distance) or 3C borehole geophone, while SH-wave borehole data by a 3C geophone (15 Hz) and a MiniVib IVI T-2500 seismic source (sweep: 12s, 10 – 120 Hz, force 1200 Lb).

In addition to the borehole data two refraction seismic lines has been acquired. The aim of this survey was the measurement the P- and SH- velocity nearby the planned tunnel portals for geotechnical purposes. Two sites were selected: the first one (MA_01) on the Malta Island nearby the borehole BH9, the second one (GO_01) on the Gozo Island nearby the borehole BH8. In both lines was utilized 24 channels spaced 10 m and connected with 10 Hz vertical geophone and 10 Hz horizontal geophone for P- and SH-wave acquisition, respectively. As for borehole data acquisition an accelerated weight drop as P-wave seismic source and Minivib in SH mode for the shear wave acquisition were adopted.

Borehole data allow to compute the seismic velocities of the geological formations present in the study area.

Velocity versus depth information were used to convert time to depth in order to assign reliable depths to the events seen in the offshore seismic reflection profiles. Further borehole data give also insight into seismic wave propagation/reflectivity and provide a guide for interpretation of the offshore seismic data.

References

Galea P. (2007). Seismic history of the Maltese islands and considerations on seismic risk. Annals of Geophysics. 50. pp. 725–740.

Petronio L., Facchin L., Zgur F., Gordini E., Baradello L., Cotterle D., Romeo R., Forlin E., Visnovic G., Deponte M., Affatato A., Coren F., Galea P., Pace S., Micaleff A., Spatola D., (2017). The Malta-Gozo tunnel project: preliminary geophysical offshore investigations. GNGTS, Trieste, S 3.2, pag. 647 – 648.