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New Directions in Seismic Hazard Assessment through Focused Earth Observation in the Marmara Supersite

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1 INTRODUCTION

1.1 MARSITE WP6

As one of the three SUPERSITE concept FP7 projects dealing with long term high level monitoring of major natural hazards at the European level, the MARSITE project gathers research groups in a comprehensive monitoring activity developed in the Sea of Marmara Region, one of the most densely populated parts of Europe and rated at high seismic risk level since the 1999 Izmit and Duzce devastating earthquakes.

Besides the seismic threat, landslides in Turkey and in this region constitute an important source of loss. The 1999 Earthquake caused extensive landslides while tsunami effects were observed during the post-event surveys in several places along the coasts of the Izmit bay.

The 6th Work Package of MARSITE project gathers 9 research groups to study earthquake-induced landslides focusing on two sub-regional areas of high interest. As part of this project, the off-shore entrance of the Izmit Gulf was studied, close to the termination of the surface rupture of the 1999 earthquake, that shows an important slump mass facing the Istanbul coastline.

As regards the selected off-shore area, high resolution geophysical marine surveys are being conducted to complete its geomorphological description to help in mapping possible incipient mass movements. This is especially expected to provide better-constrained input for both laboratory testing and numerical modeling of tsunami scenarios thank to a unique lab-scale tsunami channel.

Recall that the 6th Work Package of MARSITE FP7 project gathers 9 research groups (INERIS, IU, ITU, TUBITAK, INGV, CNR, University of Pavia, IFSTTAR - University of “La Sapienza”) to study earthquake-induced landslides, focusing on the survey and monitoring of two sub-regional areas of high interest. The research aims to improve the preparedness of those seismically induced landslide geohazards, through the using of surveying, modelling and monitoring approaches.

Second, the off-shore entrance of the Izmit Gulf was selected, close to the termination of the surface rupture of the 1999 earthquake that shows an important slump mass facing the Istanbul coastline. This area is the object of analyses for tasks 1a and 2a, and the results of these studies are showed in this report.

This deliverable summarizes the multidisciplinary scientific contribution realized in the task 1a (off-shore landslides). The work subdivision for this task was the following:

- Geological data recovery and sharing by **TUBITAK** and **ITU**;
- Collection of new marine geological-geophysical data by **ISMAR-CNR**;
- Processing and interpretation of all available marine geophysical-geological data in the study area, by **ISMAR-CNR**.
- Discovery of a new slumping body at the eastern termination of the 1999 Izmit earthquake rupture, which represent a potential hazards in term of tsunami waves for the coasts of the Sea of Marmara; this newly recognized feature was called South-Eastern Cinarcik Slump (SECS) **ISMAR-CNR**;
- Compilation of a new detailed geological map of the SECS, which includes high resolution morpho-bathymetric data as well as multichannel and single-channel seismic profiles; this map will be used to coordinate future campaigns of geotechnical measures **ISMAR-CNR**;
- Formulation of a new model to compute edge waves excited by underwater landslides **ITU**
- Preliminary evaluation of the tsunami hazard associated to the SECS for the Marmara coasts;

1.2 Backgrounds

The study of tsunamis triggered by submarine landslides has increased considerably in the last decades, mainly due to the expanded knowledge of the seafloor. In fact, the availability of powerful marine geophysical techniques, such as the development of accurate and reliable multibeam echosounders, revealed numerous submarine landslides on the seafloor surface. The observation of these features has stimulated a number of studies to evaluate the role played by such features as potential tsunami sources (Harbitz, 1992; Harbitz et al., 2006; Masson et al., 2006; Ozeren et al., 2013). The triggering of submarine landslides usually includes several factors, such as high-amplitude sea-level changes, sediment overburden, storms, gas within the sediments and dissociation of gas hydrate, as well as earthquake shaking. This latter mechanism is probably the most common case in the deep basins of the Sea of Marmara, which develops between the Northern and the Middle strands of the seismically active North Anatolian Fault (Figure 1).



Figure 1. Structural map of the North Anatolian Fault (NAF) system in the Sea of Marmara. We note how the deep basins in Marmara form along the NAF northern strand. The study area is located at the western end of the Gulf of Izmit (yellow box). Modified from Gasperini et al., 2011.

The Sea of Marmara has been site in the past of destructive tsunamis, associated to major earthquakes (AD 120, 447, 542, 558, 740, 1265, 1332, 1344, 1509, 1766, 1894, 1912) as reported in the historical catalogs (e.g. Soloviev et al., 2000). However, several lines of evidence, including structural map, focal mechanisms, mechanical models, etc., suggest that the most common displacement occurring during a major earthquake in the region is almost purely strike-slip, which in theory do not cause any (or very limited) mass movements. We can deduce, that tsunamis in the Sea of Marmara were (and probably will be in the future) caused by mass movements due to earthquake shaking.

2 METHODS

The research cruise MARMARA2013 was carried out with the *R/V Urania* (Figure 2), owned and operated by SO.PRO.MAR. The ship is employed for geological, geophysical and oceanographic work in the Mediterranean Sea and adjoining waters, including but not limited to, the Black Sea. *R/V Urania* is equipped with DGPS and SEAPATH positioning system (satellite link by FUGRO), single-beam and multibeam bathymetry and integrated geophysical and oceanographic data acquisition systems, including ADCP, CHIRP SBP and other Sonar Equipment, along with devices for water and sediment sampling. Additional equipment can be accommodated on the keel or towed.



Figure 2 The R/V Urania

The vessel was set for data acquisition and navigation with PDS-2000 software by RESON, interfaced to several sensors through a multiseriial and Ethernet link; among such instruments, the DGPS (Fugro), the Simrad single-beam echosounder, the MAHRS MRU and the meteorological station. Position and depth data were also distributed to the CTD data acquisition console.

2.1 CTD DATA

CTD casts were taken throughout the surveyed areas, for sound velocity analysis, and were used for real-time MBES acquisition and post-processing. CTD casts were carried out once in a day just before the execution of gravity coring. In order to save time, and because oceanography was not in the objectives of the cruise, data acquisition was terminated once a stable velocity/depth function was reached. This happened most often below 600 m of water depth.

Together with sound velocity, data of conductivity, temperature and oxygen were collected.

2.2 CHIRP SBP

SBP data was acquired by the 16 transducers, hull mounted BENTHOS (DATASONICS) Mod. CHIRP-III profiler, with operating frequencies ranging between 2 and 7 kHz. The pulse length was selected between 5 ms and 15 msec, while the trigger rates varied from 0.25 to 1.5 seconds, depending on water depths. Data were collected using the *mutiping* techniques, *insonifying* the water column with several chirp-sonar pings. Digital data acquired by the *Communication Technology* SWANPRO software, were recorded in the XTF format on local disks and transferred on the network upon request. Backups were loaded on external HD. Navigation data were made available to the system as lat/long by NMEA sentences of the DGPS receiver at a rate of approximately 1 Hz or by the PDS2000's NMEA at 1Hz. The XTF data were then converted to SEG-Y using the SeisPrho software [Gasperini and Stanghellini, 2009], also employed for compiling BMP images of the seismic profiles onboard. An example of Chirp-Sonar profile processed with SeisPrho is shown in Figure 3.

2.3 Multibeam Echosounder (MBES) DATA

Swath bathymetry was collected using a RESON 7160 MBES.

The MB sonar head is positioned on the ship's keel using a V-shaped steel frame. A Sound Velocity probe at the keel 1m above the Sonar Head is interfaced directly to the MBES processor, thus providing the necessary real-time data for the beam-forming. CTD casts were used for input of the sound velocity profile to the system. All the function of the MBES are controlled by the RESON software which provide quality control of the data and information for planning the survey.

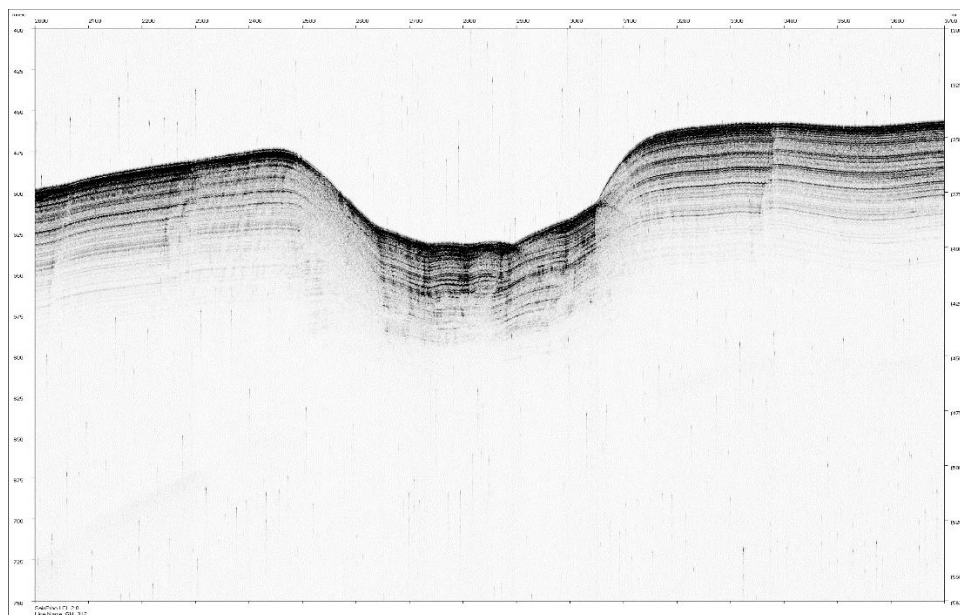


Figure 3. Example of Chirp-Sonar profile collected in the study area showing active faults.

2.4 MULTICHANNEL SEISMIC PROFILES

The acquisition of multichannel seismic reflection profiles was carried out using the equipment of the IGM's mobile laboratory (IGM 2) that was located at the ship's stern. An ES2420 (Geometrics) was used to acquire seismic data. This final configuration allowed the acquisition of seismic data according to the following parameters:

12 acquisition channels spaced 50m	24 acquisition channels spaced 25m
50 m shot interval	50 m shot interval
1 msec of sampling rate	2 msec of sampling rate
12 seconds of record length	12 seconds of record length
14 bits of dynamic range	14 bits of dynamic range
90 Hz of anti aliasing filtering	90 Hz of anti aliasing filtering
10 Hz of low cut filtering	10 Hz of low cut filtering

The seismic source consisted of an array of two G.I. guns (Sodera) towed at a depth of 6 m. Each gun has a capacity of 105 cubic/inches for the generator chamber, as well as for the injector; they operated at a pressure of 100-140 bars in harmonic mode. The receiving streamer (Teledyne) was formed by 24 channels (20 hydrophones each), 25 m spaced; the nearest channel was located at 150 m from the seismic source. The shot interval was 50 m, allowing a coverage of 600%. Multichannel lines were run at a speed of 4.5-5 knots. Positioning of the shot stations (50 m of interval) was automatically performed by the navigation software, NAVMAP, connected to the G.I. guns synchronization system. This device, developed at the IGM's electronic laboratory, provides the automatic synchronization of an array of GI guns (up to 4 guns), taking into account natural delays of the shot-triggering valves (2 for each gun, Generator and Injector) by cross-correlating the nearfield signature recorded through a hydrophone mounted on each gun.

2.5 SEDIMENT SAMPLING

Sediment samples were collected with a 1.2 t gravity corer (Figure 4). The corer was armed with a 1.2 T of weights and one 6 m-long pipe. A trigger was used to gather the maximum impact speed of the corer at the seafloor.



Figure 4. The 1.2 t gravity corer armed before a coring.

2.6 DATA PROCESSING

Georeferencing of the data was performed relative WGS84 datum, in UTM33N and 34N projections and time in UTC. Time zone was set to the UTC for the data acquisition. Positioning maps and bathymetric images were produced with GMT [Wessel and Smith, 1991] and Global Mapper. Multibeam data were processed using CARIS software and ISMAR's routines and scripts, using the SIS production DTMS, after conversion to the ASCII format. Bathymetric data were complemented by SRTM plus data available at the web page: topex.ucsd.edu/WWW_html/srtm30_plus.html. The computing center employed INTEL based PC running the GNU-Linux in addition to portable computer for data acquisition and personal processing. The Linux machines were used as data repositories using the SAMBA software, providing also network services like WWW, DHCP and NAT.

Seismic reflection data were analysed and interpreted using SeisPrho (Gasperini and Stanghellini, 2009).

3 THE SOUTH-EASTERN CINARCIK SLUMP (SECS)

Marine geophysical data collected in the Sea of Marmara during several oceanographic cruises carried out since the 2000, highlighted the presence of a large (several km wide) slumping body located in southern slope/shelf of the Cinarcik Basin, at its connection with the Gulf of Izmit (Eastern Sea of Marmara). The study of such feature, we call South-Eastern Cinarcik Slump (SECS, Figure 5) has been considered important to evaluate the geological hazards of the region, because large-sized, and located close (or above) to the western termination of the 1999 rupture of the 1999, Mw7.4 Izmit Earthquake. Moreover, the slump body is located in relatively deep waters (up to 1000 m) and in front of a highly populated area (Tusla-Eastern Istanbul).

3.1 TSUNAMI HAZARDS

A possible scenario is that, due to a future earthquake that will most probably occur in the so called Cinarcik Segment, the large body could be destabilized, causing a tsunami: defining the dimension of the potentially sliding body is the first step to provide an estimate of the expected magnitude and likely consequences of such event.

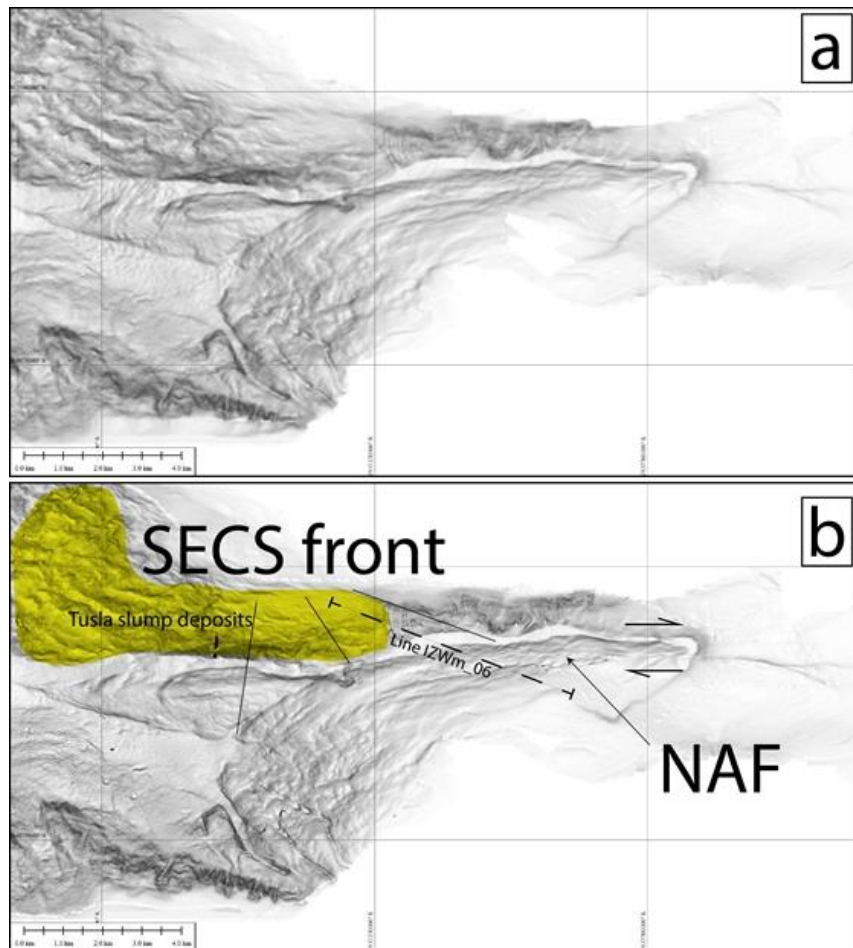


Figure 5 Slope map of the 25m (a) and the newly collected, 10 m (b) available for the SECS. Main morphostructural elements are indicated, as well as the track of the NAF cutting through the slumping front. Dashed line indicate the position of MCS line IZW_06m shown in Figure 6.

To gather a reliable Digital Terrain Model (DTM) of the seafloor in the Eastern Cinarcik Basin, over the SECS, which is the subject of our study, we performed an accurate processing of the Multibeam echosounder (MBES) data collected during the cruise MARMARA2013. First, we imported the data in *Caris*, the software package we use for MB data processing. Then, we applied all corrections, including, sound velocity, attitude of the ship (heading, tilting, rolling) and to the errors of navigation. Particular attention has been devoted to calibration with sound velocity curves, particularly critical in the Sea of Marmara due to its complex oceanographic setting. We then applied all statistical corrections to the array of points that was initially calculated by the *beam forming* algorithm to exclude the erroneous quotes. Finally, we carried out a manual control of each swath to eliminate the residual errors. Result of such operation was a high-resolution DTM of the Eastern Cinarcik Basin, shown in Figure 5b.

Sediment cores collected on top of the SECS confirm it is made by upper Pleistocene marine/lacustrine sediments, consisting of alternating hemipelagic mud and fine grained sand, deposited in the basin as a consequence of turbiditic flows. Thus, the mechanical properties of the sediment is very poor, as also undelined by the presence of high-amplitude reflector in the MCS and CHIRP sonar profiles

We also carried out a detailed processing of MCS seismic lines collected during MARMARA2001 geophysical cruise (<http://www.ismar.cnr.it/prodotti/reports-campagne/2010-2019>). The re-processing was mainly devote to highlight the morphotectonic feature characterizing the SECS at depth and infer its geometry and deformation pattern. MCS data processing included: 1) deconvolution; filtering; time-migration.

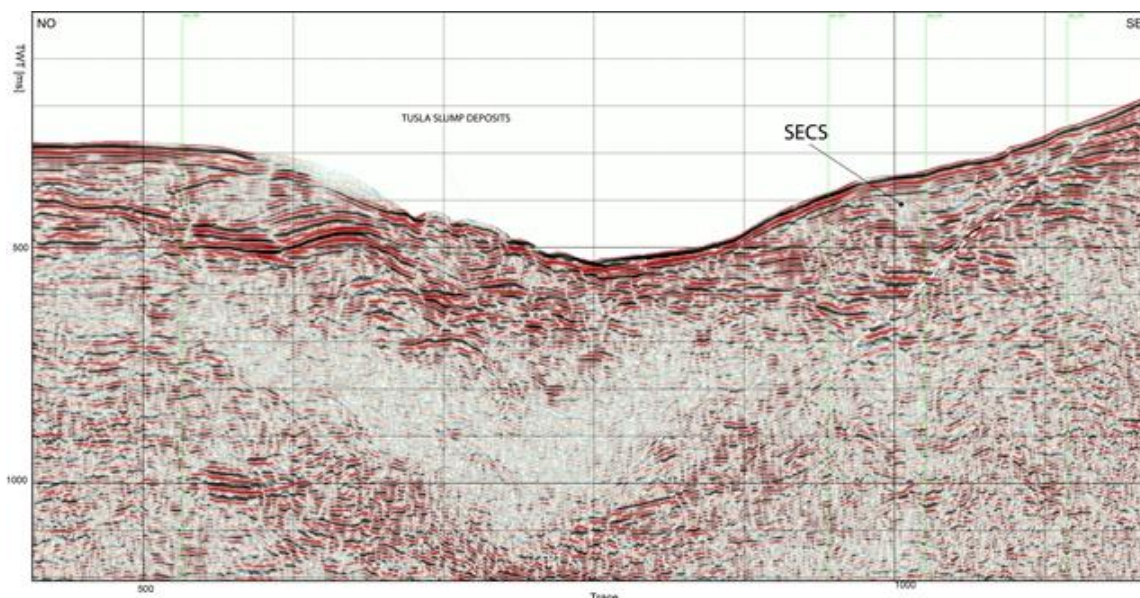


Figure 6 NW-SE oriented MCS line IZW_06m crossing orthogonally the SECS. We note how the movements of the slumping/creeping main body is controlled by the presence of high-angle NW dipping normal (transtensive) faults (white dashed line).

MCS seismic line IZW_06m displayed in Figure 3 cuts orthogonally the SECS and shows interesting details of its structure at depth. We note the presence of high-angle extensional

(probably trans-tensional faults that displace the basin slope dipping towards N-NW (dashed white line in Figure 3), and a sub-horizontal ramp at the base of the slumping body. Using MCS data, and assuming reasonable values for the p-wave velocity for the surface deposits (2000 m/sec) we could estimate a maximum thickness of 200-250 m for the SECS.

In Figure 5, the 25m DTM available before MARMARA2013 (a) is compared with the new DTM (b) collected during MARMARA2013 expedition (<http://www.ismar.cnr.it/prodotti/reports-campagne/2010-2019>). We note how the higher resolution of the morphobathymetric data presented in Figure 5b enable us to recognize several features of the SECS not visible in the DTM of Figure 5a, including: 1) the track of the 1999 rupture along the NAF that cross cut the slump front; 2) the slope breaks located parallel to the SECS front, which denotes differential creeping movements downslope; 3) the presence of minor, very fresh slump scars, possibly related to the shaking caused by the last Mw 7.4 1999 Izmit earthquake; 4) the presence of a series of gullies and canyon cutting the SECS and connecting to the deeper Cinarcik basin.

Analysis of all available data led us to map the SECS, estimate its dimensions (25 km² of extension; 250 m of maximum thickness) and figure out a possible (or some possible) scenario in case it will be mobilized by a future earthquake that will struck this region in the next decades, according to accepted geological models. Next step will be modelling the effect of a major slump in correspondence of this feature in terms of tsunami waves affecting the highly populated coasts of the Eastern Marmara region.

4 CONCLUSION

The South-Eastern Cinarcik Slump (SECS) was recognized, studied and analyzed in terms of tsunami hazards for the coast of the Sea of Marmara (NW Turkey). We note that the SECS is located close to the western termination of the 1999, Mw=7.4 Izmit earthquake, and for this reason it is most probably close to the epicenter of the earthquake that according to recent studies will struck Istanbul in the next decades. Our estimate indicates a plurality of possible scenarios, because if the extent of the slumping body is well constrained (25 km² by 250 m of maximum thickness), the internal geometries suggest multiple gliding planes. These uncertainties heavily affect any possible estimate of the tsunami hazard associated with the possible failure of the SECS due to future earthquakes along the so called Cinarcik segment of the North-Anatolian Fault system in the Sea of Marmara. This however should encourage further studies of the SECS using geotechnical methods.

The main result of this WP will be published as a series of papers, including:

-Gasperini L., et alii, (2013) MARMARA2013 cruise report. ISMAR-CNR Technical report, Bologna pp. 52. (<http://www.ismar.cnr.it/prodotti/reports-campagne/2010-2019>)

- Özeren M.S., N Postacioglu, U Canli, L Gasperini, 2014. Edge waves excited by underwater landslides: scenarios in the Sea of Marmara EGU General Assembly Conference Abstracts 16, 596

- Gasperini et al., (in prep.) Study of the large slumping body in the SE Cinarcik Basin (Eastern Sea of Marmara) along the North-Anatolian Fault system. Natural Hazards

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