An integrated approach for monitoring soil settlements at the VIRGO site

A. Paoli, EGO - European Gravitational Observatory, Pisa, Italy
M. Marsella, C. Nardinocchi, S. Scifoni, C. Violante, DICEA - Survey Lab, Univ. di Roma "La Sapienza", Italy
L. Vittuari, DICAM, Università di Bologna, Italy

Abstract

The **Virgo** detector is a Michelson interferometer aimed at the gravitational waves research. It is made of two orthogonal arms being each 3 kilometers long and is located at the site of the European Gravitational Observatory (EGO), in the countryside near Pisa, Italy.

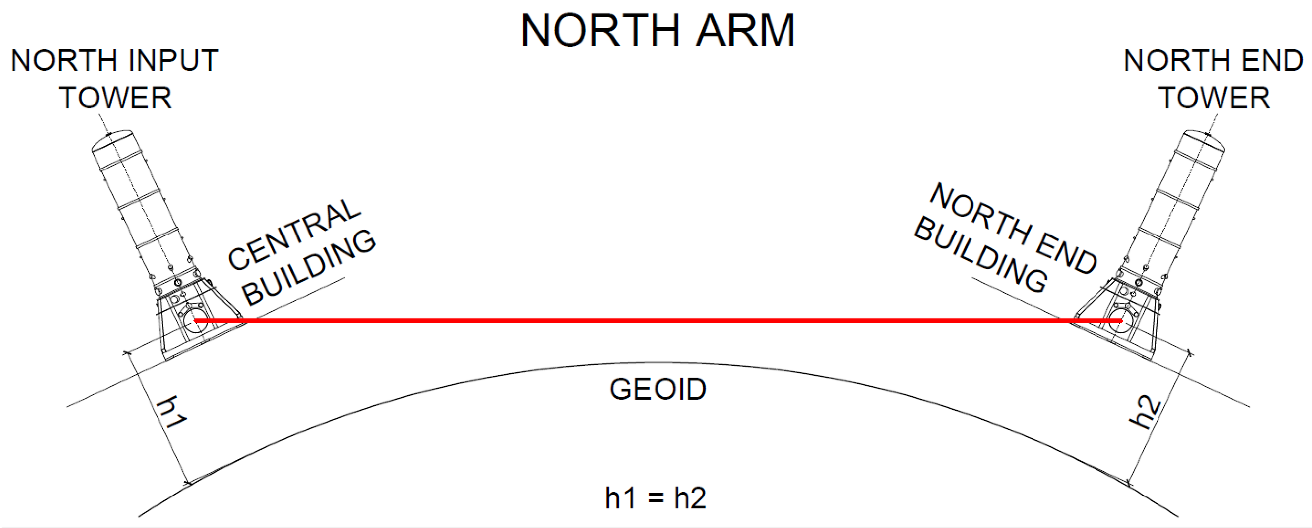
After the construction of the Virgo facilities completed in 2002, over the years a steady subsidence process has been observed as a consequence of the building and embankment overloads.

Monitoring activities conducted over the years, mainly consisting of regular **high accuracy levelling** surveys, periodically integrated by **GPS** and **classical theodolite** measurements, are illustrated. These sets of measurement were adopted to perform the **Virgo realignment** procedure needed to keep the interferometer rigidly tied in a 3x3km plane.

In order to improve the knowledge on the trend of the settlements affecting the Virgo infrastructures, an analysis based on differential interferometry using satellite **Synthetic Aperture Radar (SAR)** data has been performed and compared with the outcome from in-situ data.

Monitoring activities

- Systematic high accuracy levelling
- Periodically integrated by GPS
- Classical theodolite measurement

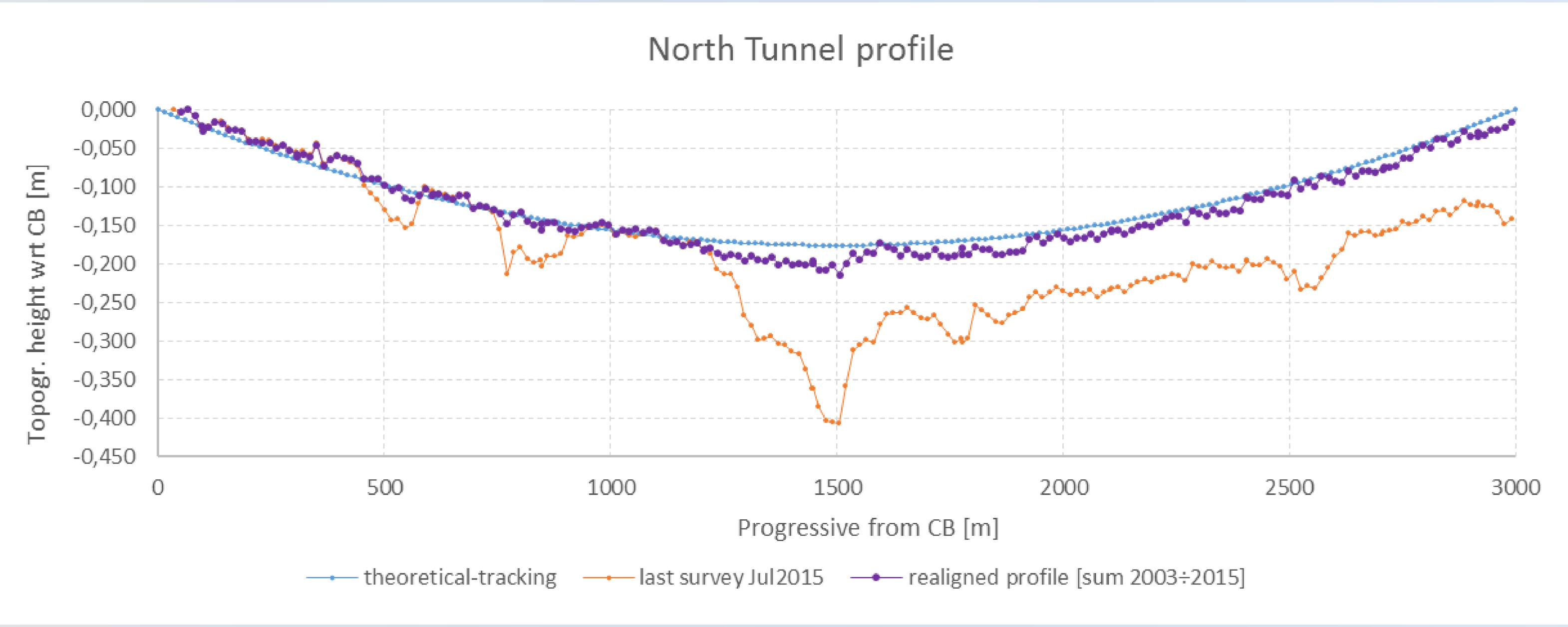


These sets of measurements were adopted to perform the Virgo realignment procedure needed to keep the interferometer rigidly tied in a 3x3km plane. In order to apply the required correction, the vertical displacements measured along the arms were reduced in a relative reference system with respect to the optical center of the interferometer located in the Central Building.

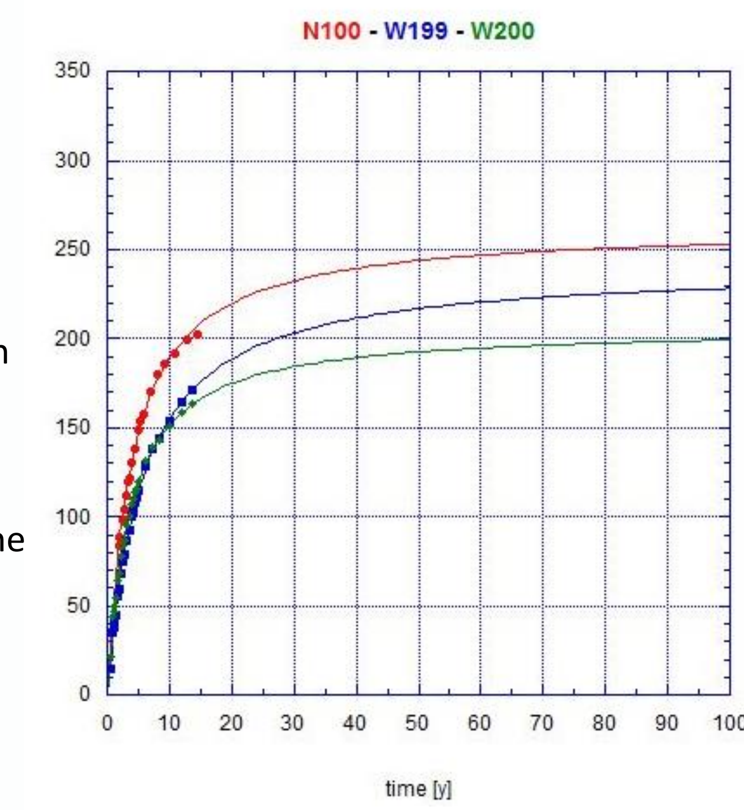
Realignment procedures have to be carried out when the relative displacement of one tube modules is higher than 5mm with respect the previous survey. This value becomes 2mm for the special modules linked to the large vacuum tube valves, close to the experimental buildings.

Settlement data analysis

Last survey of the tunnel profile is compared with the theoretical design position and the tube axis profile effectively realigned, sum of the operations since the start of the realignment process.



The amount of data collected during the years allows the evaluation of a possible scenario of the phenomenon.
A best curve fitting analysis of the surveyed data has been performed for the tunnel areas showing the most pronounced effects.
Particularly, these are located in the middle part of the North Tunnel (reference point N100) and in the zone of the West Tunnel next to the West End Building (reference points W199 and W200).



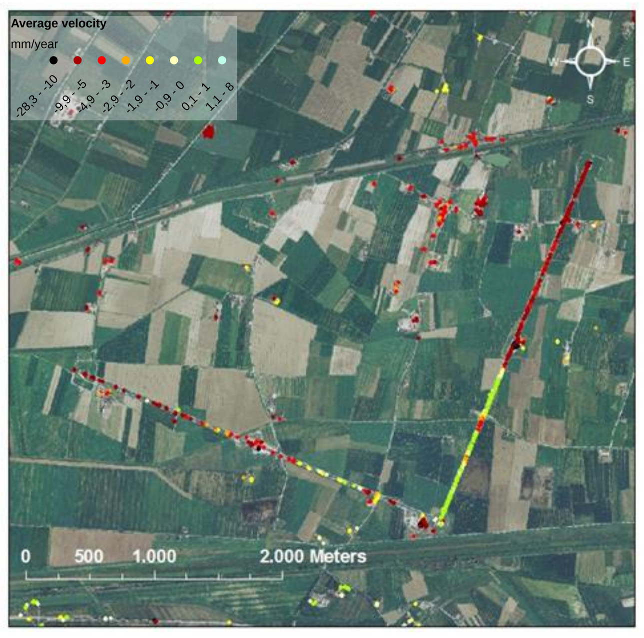
y = m1*x/(m2+x)	Value	Error
m1	263.08	2.6928
m2	3.9333	0.099495
Chisq	70.999	NA
R^2	0.99725	NA

y = m1*x/(m2+x)	Value	Error
m1	240.83	2.4282
m2	5.5361	0.11246
Chisq	44.475	NA
R^2	0.99897	NA

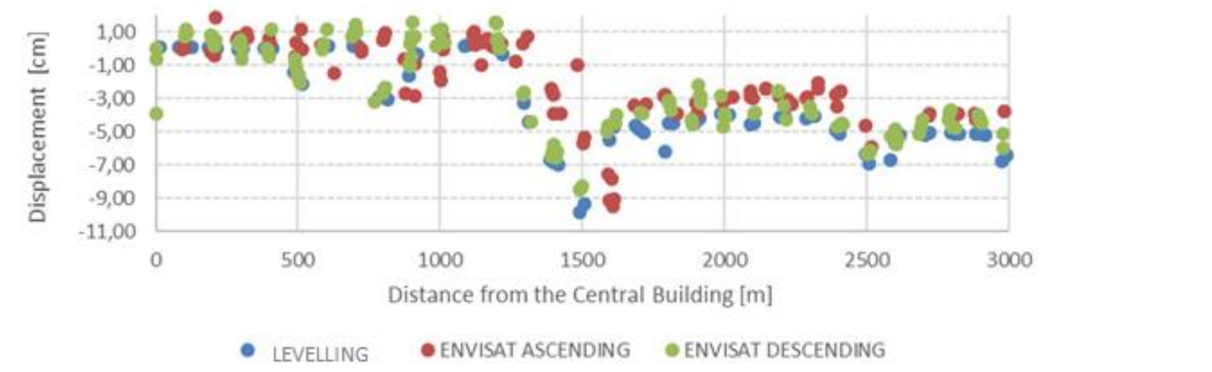
y = m1*x/(m2+x)	Value	Error
m1	206.53	1.6525
m2	3.63	0.06823
Chisq	42.082	NA
R^2	0.9988	NA

DinSAR data analysis

Differential Synthetic Aperture Radar Interferometry (DInSAR) is a technique based on remote sensing data able to detect ground displacements. It relies on the processing of the phase difference (Interferogram) between two temporally separated SAR images. In particular, advanced DInSAR approaches are based on the processing of SAR acquisition sequences collected over large time spans to generate displacement time series of permanent scatters (PS). DInSAR time series, obtained processing ENVISAT data from January 2003 to June 2010 (provided by the Italian National Geoportal of the Ministry of Environment and Protection of Land and Sea), were analysed for the surrounding area of the Virgo interferometer.
RGB colour scale shows stable area (in green) and unstable area characterized by subsidence phenomena (in red).



The DInSAR cumulative displacements were compared with levelling data. The two different techniques revealed comparable subsidence trend. The displacements derived by the DInSAR data, although less accurate than the levelling ones, are characterized by larger ground coverage that allows to make an assessment of the ground subsidence phenomena at large scale.



Conclusion

A significant subsidence phenomenon has been observed in the Virgo Area through a regular monitoring activity.

Regular campaigns of high-accuracy levelling measurements were conducted over time, in order to assist the realignment procedures and fulfil the geometrical and technological specification set for the 3+3 km vacuum tubes hosting the laser interferometer.

Periodically, such campaigns are also integrated by GPS and theodolite measurements for checking planimetric displacements.

The monitoring dataset has permitted to quantify the evolution of a relevant subsidence process induced by the overloads of the Virgo structures acting on compressible soils at foundation.

In order to understand the overall settlement process, the evaluation of the deformation patter of the Virgo Area has been performed also through the DInSAR technique. The comparison between the subsidence evaluated using DInSAR analyses and the direct measurement by levelling provided a significant coherence in the evaluation of the general trend along the tunnels.

Contacts: **Andrea Paoli** - andrea.paoli@ego-gw.it - EGO | **Silvia Scifoni** - silvia.scifoni@surveylab.info - Survey Lab | **Maria Marsella** - maria.marsella@uniroma1.it - DICEA Sapienza University