Monitoring the stability of infrastructures in an emergency scenario: The “Costa Concordia” vessel wreck

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ABSTRACT: We present a summary of the monitoring activities performed by CNR-IRPI during the emergency scenario relevant to the “Costa Concordia” ship stranding, occurred on January 13, 2012, near the coast of Il Giglio Island, Italy. Two Robotized Total Stations (RTS) were deployed in different times in order to monitor the stability of the vessel during the Search and Rescue activities, as well as the fuel recovery accomplishment. RTS data have been considered as an important support for the early warning system set up to ensure the safety of the operators. The dataset and results herein included are unique, and represent a peculiar and concrete opportunity to test the efficiency of specific monitoring techniques, which were developed to control and study phenomena relevant to engineering geology activities, also in very peculiar structural health’s monitoring, relevant to an unforeseen emergency scenario.

1 INTRODUCTION

On January 13, 2012, the “Costa Concordia” cruise vessel ran aground off near the coast of the Il Giglio Island, Italy (Fig. 1). More than 4,200 passengers were on board, and the incident caused 30 casualties. This event was probably the largest and most impressive passenger ship stranding occurred in the last centuries.

In the event aftermath, the Italian Civil Protection Department (DPC) coordinated the emergency phases, which were characterized by various and complex operations. The cruise ship is long about 300 m, weights more than 50,000 tons, with 5% of the load being fuel, which after the vessel stranding could potentially contaminate the seawater and the coastal environment in one of the most beautiful touristic places of the Mediterranean. The hull partially sunk and tilted to one side of about 65 degrees, and finally accommodated on the granitic seafloor characterized by an inhomogeneous bathymetric profile. In this critical scenario, the DPC activities included (Fabri, 2012): (i) recovery of missing persons (two people still missing at the moment of writing); (ii) ensuring the safety of the Search and Rescue (SaR) activities; (iii) supporting the fuel removal operations to avoid seawater contamination (iv) supervising the hull’s recovery accomplishment.

In order to ensure the safety of the SaR operations, as well as to support the fuel removal activities, one of the main issues was relevant to analysis of the stability of the stranded ship on the seafloor. Therefore, a monitoring network was installed to measure potential movements and/or deformation of the ship. The “target” and the scenario to monitor was unusual, thus, a specific system and/or straightforward procedure was not directly available. For this reason, the monitoring approach was derived from other disciplines, and mainly from methods that are typically used in engineering geology applications.

Monitoring activities were coordinated by DPC through the Department of Earth Sciences of the University Florence (DST-UNIFI). The integrated system employed to monitor the ship’s stability included (Fabri, 2012): (i) two accelerometers installed on board of the vessel, and operated by

Figure 1. The Costa Concordia vessel wreck after its run aground off near the Il Giglio island. The position, as well as the field of view of the two RTS monitoring stations is also indicated.
Neri/SMIT and SIRI-Marine; (ii) two Robotized Total Stations (RTS), operated by CNR-IRPI; (iii) a new generation Synthetic Aperture Radar interferometer, installed and operated by Joint Research Center of the European Commission; (iv) a terrestrial LiDAR installed and operated by DST-UNIFI; (v) three seismic stations to monitor micro seismicity, installed and maintained by FPR-INGV; (vi) Analysis of space-borne SAR data, performed by ASI, TRE, Polytechnic of Milan; (vii) two GPS receivers installed on board of the vessel, operated by HERA.

The expected vessel's movements were relevant to deformation of the superstructure; however, displacements associated with sliding of the hull on the seabed could not be a-priori excluded, especially during extreme weather and marine conditions. Thus, a set of markers was placed on the sea floor in contact with the hull, periodically controlled by divers of the Italian Coast Guard and State Police.

The combination and integration of the above-described monitoring techniques was essential to provide an early warning system, which has been applied during both SaR activities and fuel recovery operations. In addition, the data collected and the interpretations were made available to the operators involved in the emergency scenario via daily bulletins, in order to support authorities and decision makers in their activity planning.

In this work, we focus the attention on the activities and results based on the measurements performed by the Research Institute for Geological Protection of the National Research Council (CNR-IRPI) on the Costa Concordia cruise vessel. As Centre of Competence for DPC, CNR-IRPI is often involved in emergency scenarios relevant to landslide and other geohazards. In this specific case, the CNR-IRPI monitoring network during the Costa Concordia emergency was based on two Robotized Total Stations, installed at different times, which controlled the position of targets installed on the emerged portions of the hull.

2 RTS MONITORING NETWORK

Robotized Total Stations (RTS) are modern theodolites coupled with precise laser distance meters that can measure automatically the position of artificial targets (usually optical prisms), by measuring three parameters: a vertical angle (Vz), a horizontal angle (Hz) and a distance (d). The targets are installed so that the optical Line-Of-Sight (LOS) towards the RTS can be maintained over time.

The Geohazard Monitoring Group (GMG) of CNR-IRPI is in charge of monitoring systems used as key elements to support DPC for early warning purposes, and thus protect vulnerable targets. The approaches presented here and applied on the Costa Concordia event have been developed during several years of experience performed in different contexts, including mainly landslides, but also seismogenic areas, open-pit mines, etc. (e.g., Allasia et al., 2009, Manconi et al., 2012, Giordan et al., 2013).

At Il Giglio Island, GMG installed the first RTS system on January 19, 2012, and more specifically at the location known as “Punta Gabbianara” (RTS-1, see Fig. 1). This monitoring system is still operating at the moment of writing. The network is based on a Leica TM30®, which measures the three-dimensional position of 12 targets (optical prisms) mounted directly on the Concordia hull (see positions in Fig. 3a), and 4 reference points installed on stable ground. The measurements were performed 24 hours a day, with revisit times ranging from about 15 minutes to 2 hours. Estimated accuracies of the RTS measurements for this monitoring network configuration are in the order of ±1 mm.

The RTS-1 is one of several instruments installed at Punta Gabbianara to monitor displacements and/or deformation (see section 1). Thus, redundancy, as well as cross-validation of the monitoring data was possible. The daily analysis and comparison performed by DST-UNIFI (not shown here for brevity) confirmed that the displacement measurements obtained via RTS-1 are well in agreement with the observations performed via the other independent instruments used, such as ground-based SAR, Terrestrial LiDAR and GPS. From the Punta Gabbianara position, the emerged portion of the vessel could be well monitored on the western side (towards the coast). However, this was only partial view, as the eastern side (towards the sea) was not visible and could be not monitored. Space-borne SAR data acquired via the Italian Cosmo-Skymed (CSK) satellite constellation have been considered as a remote sensing solution to retrieve eventual displacements. However, revisit time was not suitable for early warning purposes in such a critical scenario. In order to solve this issue, a second Leica TM30® has been installed on February 13, 2012, at the location named “Punta Saraceno” (RTS-2, see position in Fig. 1). CSK and the RTS-2 are the only two monitoring sensors able to control displacements on the eastern side of the vessel. Due to clear logistical problems, the optical prisms could not be installed on that side of the vessel in a standard way, i.e. through screws and/or fasteners. For this reason, the targets were installed on the hull by using magnets. The data obtained from the RTS-2 have a different level of accuracy (±5 mm), as the mean distance from the target was larger (more than 1 km vs. 0.2 km for the RTS-1 configuration) and air refraction variations are more influenced by the seawater.
However, by analyzing and integrating the data obtained from the use of two RTS stations it has been possible to better control the stability of the vessel and its evolution over time.

2.1 Monitoring results and early warning

Here we show the RTS monitoring data retrieved by RTS-1 and RTS-2 in the period 20/01/2012–31/05/2012. RTS data were shared with the operators working during the emergency scenario in the standard form of bi-dimensional charts representing the time series of the planimetric and altimetric displacement revealed at each monitored target (Fig. 2). By looking at the results, it is possible to note that the position of the targets varied over time, with amplitudes that are larger on points located at the bow.

Zooming on a the time series, it is possible to observe daily oscillations due to thermal dilation and/or sea tides. In addition, during severe weather conditions, the targets experienced some accelerations that were well captured by the monitoring system.

In order to better understand RTS data, monitoring results were also plotted and divulged in an original manner. This approach has been developed by GMG mainly for geohazard scenarios, but it has been very useful also for the correct analysis and a subsequent interpretation of the deformation data in this particular case (Fig. 3). This typology of output is produced via a software suite, namely Three-dimensional Displacement Analysis (©3DA), which complements the standard representation of the results with a three dimensional representation of the surface deformation in near-real-time (Manconi et al., 2013). The results of the ©3DA algorithm can be projected on and referenced to a real (photo) and/or realistic (digital model) representation of the region of interest. Information on the intensity and real direction of the surface displacement is represented by 3D vector arrows. In addition, ©3DA might be used to recognize points and areas overcoming magnitude thresholds and consequently act according to predefined operations, such as for example send warning/alarm messages when a critical displacement is reached.

For both the RTS networks, we set up automatic procedures that allow going in near-real-time from the acquisition of displacements data on a
monitored target to the efficient divulgation of the results via WEB. This straightforward procedure adopted by GMG is called ADVICE (ADVanced dIsplaCement monitoring system for Early warning), and is currently applied in several emergency scenarios relevant to geohazards (Allasia et al., in prep.). After the measurements sessions and the data processing, the results are automatically uploaded on a dedicated “LiveData” webpage, hosted at the address http://gmg.irpi.cnr.it/. By using this approach, accredited user may promptly consult the monitoring data in near-real-time.

In several geohazard scenarios, as well as in the emergency relevant to the Costa Concordia vessel wreck, we experienced that the use of ADVICE has speed-up and facilitated the understanding of the evolution of displacements over space and time. Moreover, the communication of the monitoring results to partners and DPC operators was also eased, and consequently the decision-making chain in critical situations.

3 DATA ANALYSIS

The main purpose of RTS monitoring was to warn operators in case of accelerations that could affect the stability of the vessel structure. However, the monitoring results can be used also to better understand the general behavior of the Concordia vessel wreck. The observed displacement time series may lead to several interpretation hypotheses: (i) progressive deformation of the hull; (ii) roto-translation of the hull on the seafloor; (iii) a combination of (i) and (ii).

In order to test the scenarios (i) and (ii), we calculated the surface area and the volume of a simplified polyhedron described by the three-dimensional coordinates of selected targets relevant to both RTS monitoring networks, more specifically the points P1, P6, P7, and P10 of RTS-1 network, and E2 and E8 of RTS-2 network. Considering the 20 January 2012–31 May 2012 time period, the size of the polyhedron changed over time: its surface area and volume decreased of about 3%. Although this calculation is a first order approximation, our result seems to confirm the hypothesis that the majority of the measured displacements were related to the deformation of the hull. The latter has been likely caused by the particular stress conditions acting on the hull structure, which accommodated in a unnatural position on top of granite rocks located in the seafloor. In addition, daily fluctuations of sea tides, as well as larger oscillations of the hull during adverse weather and marine conditions, played probably a role in the evolution of the deformation process. On the other hand, rotation components and/or sliding of the vessel on the seabed cannot be completely excluded. However, roto-translation was probably negligible in the observed time period, as also the controls performed by divers on the markers placed on the seafloor testify only minor changes.

4 CONCLUSIONS

In this paper, we present a summary of the monitoring activities performed by CNR-IRPI during the emergency scenario relevant to the “Costa Concordia” run aground off the Il Giglio Island on January 2012. We described the integrated monitoring network, composed by 2 RTS, a set of 23 optical prisms mounted directly on the hull, and 4 reference points installed on stable ground. Our work shows that monitoring approaches and procedures developed and mainly applied in contexts relevant to geohazard scenarios, and more in general to engineering geology activities, can be well adapted and efficiently used also in a unique case-study as the emergency relevant to the Concordia vessel. The availability of accurate near-real-time data allowed to increase the efficiency of the integrated early warning system set up for DPC operations, ensuring redundancy to the other available monitoring techniques. The accurate 3D displacement data acquired at high frequencies by two RTS allowed to efficiently study the evolution of the retrieved displacement data. The results of our analyses show that, most likely, the largest percentage of the measured displacements has been related to deformation of the relict's structure in the considered time period.

At this stage, the hull’s recovery operations are still in progress, and monitoring activities will continue also during the planned parbuckling stage. This will furnish to the operators additional indications about the overall stability of the Concordia superstructure throughout one of the most critical phases of the hull’s recovery project.

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REFERENCES


