

Brief communication

“Analysis of deformations in historic urban areas using terrestrial laser scanning”

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Received: 1 December 2008 – Revised: 30 July 2009 – Accepted: 6 October 2009 – Published: 2 November 2009

Abstract. The terrestrial laser scanning (TLS) technique has been used to accurately reconstruct the 3-D shape of the walls and bastions of the historic city of Mdina (Malta) and underlying terrain. By applying this technique it has also been possible to extract additional quantitative information regarding weathering and deformational processes affecting the structures. Thus, with the aim of identifying the main instability mechanisms, a detailed 3-D crack distribution map has been drawn and the main displacement vectors have been defined.

1 Introduction

Mdina, the former capital of Malta, is an old city located in the centre of the island. It is built on the top of a 5–6 m thick rigid limestone plate (Upper Coralline Limestones) (Fig. 1) overlying a thick clayey layer (Blue Clay) (Pedley, 1993). Over the years, the city has been influenced by many cultures. In 1693 it was extensively damaged by the Val di Noto (Sicily) earthquake (Galea, 2007), and most of the buildings and bastions were constructed afterwards (De Lucca, 1993).

The geological setting of the area is responsible for the occurrence of several damages on many buildings and bastion walls located in the perimetral sectors of the city (Baratin et al., 2001; Bonnici et al., 2008).

2 Methodology

The laser scanning survey has been performed with the aim of constructing a 3-D digital model of both the damaged structures and the slopes of the study areas (Fig. 2).

The employed instrument is a long range 3-D laser scanner (RIEGL LMSZ410-i). To completely cover the areas of in-

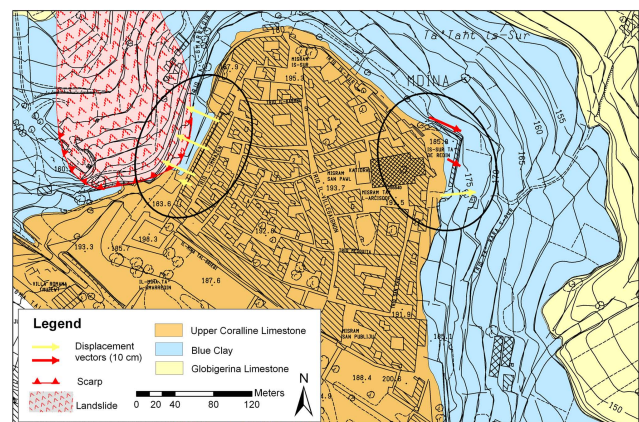


Fig. 1. Geological map of Mdina and displacement vectors (scaled to the length in legend). Yellow arrows indicate sub-horizontal displacement (dip < 15°); red arrows represent vectors dipping > 15°. Left circle: Curtain Magazines; right circle: Despuig Bastion and Cathedral.

terest, a total of 56 surveys from diverse positions have been performed. The different point clouds have been linked to a project reference system with the aid of reference points, the coordinates of which were defined by differential GPS. The high detail of the point clouds, integrated with high resolution digital images acquired by the camera mounted over the instrument, allowed the construction of a 3-D map of the main cracks affecting the structures by digitizing 3-D polylines over the crack traces (Fig. 2). Displacement vectors have been calculated for the main cracks, with the aim of identifying the structural deformation patterns. Each vector has been drawn by joining two homologue points selected from the 3-D point cloud. These were supposed to be occupying the same location before displacement has occurred (Fig. 3). Displacement vectors have been thus calculated from the director cosines and plotted on the map (Fig. 1). The



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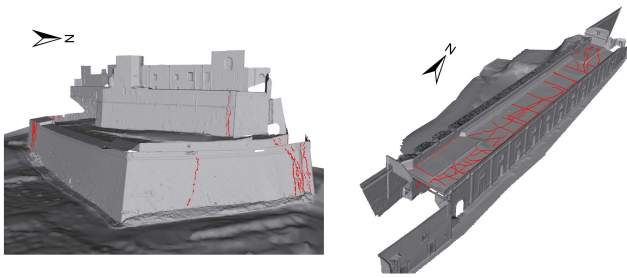


Fig. 2. Crack distribution on 3-D models obtained from TLS data. Left: Despuig Bastion; right: Curtain Magazines.

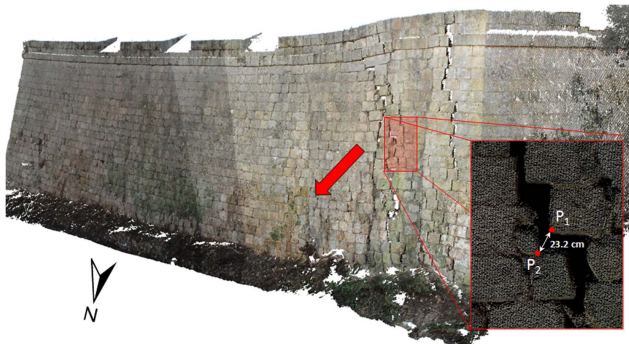


Fig. 3. Displacement vector calculation on true colored point cloud of the NE wall of the Despuig Bastion (Fig. 1). The red arrow on the wall indicates the movement direction.

integration of displacement data, 3-D distribution of cracks, and geologic, geomorphologic, and geo-mechanical surveys, allowed us to understand the basic kinematic behavior of the structures in the study area.

The proposed methodology can be applied in areas with lack of data and it allows to quickly extract the required geometrical information by post-processing remotely acquired data.

3 Discussion

Two areas affected by instability processes are reported in Fig. 1. A direct correlation with the geological and geomorphologic settings is evident. In the Despuig Bastion area a predominant translational displacement with direction E-SE is associated to a considerable vertical component. This behavior is in accordance with the geological setting hypotheses, as the bastion is supposed to be constructed just on the contact between the Upper Coralline Limestone and the Blue clays. The Curtain Magazine area is characterized by an intense concentration of cracks, most of which show displacement vectors with sub-horizontal direction and apertures up to 20 cm. Figure 1 reports the upper boundary of an area interested by a slope instability process, as observed from aerial images. This landslide is supposed to play a signifi-

cant role on the structure instability, undercutting the limestone plate in the foundation area. Based on these evidences, a specific monitoring system and peculiar consolidation interventions are being designed.

An interferometric analysis of space-borne SAR images (Ferretti et al., 2001) is also in progress, in order to reconstruct the history of deformation starting from 1992. With this technique we can obtain the displacements (along the satellite line of sight) with millimetric accuracy. These will be corrected according to the detected actual direction of movements. The integration of advanced monitoring and survey techniques (El-Hakim, 2001; Mills and Barber, 2004) represents an innovative approach for the analysis of the displacements of objects with complex shapes.

4 Conclusions

The Laser Scanning technique is more and more used for instability analyses in cultural heritage sites (Boehler et al., 2001; Arayici, 2007; Lambers et al., 2007; Yastikli, 2007; Al-kheder et al., 2009), as it allows to obtain, in a short time, a detailed and high accuracy 3-D representation of both the ground and the structures built on it. We applied this technique in order to reconstruct the 3-D model of some areas of the city of Mdina, which are experiencing serious instability problems. Thanks to the high resolution of the point cloud we have been able to draw an accurate 3-D map of cracks, the main displacement vectors of the structures and to identify the associated instability mechanisms.

Acknowledgements. This study has been performed within the “Service Contract for the provision of geotechnical engineering consultancy and project management services in relation with the consolidation of the terrain underlying the bastion walls and historic places of the city of Mdina”, funded by the ERDF for Malta and carried out by a consortium led by Politecnica Ingegneria e Architettura for the MRRA, Works Division, Restoration Unit, Floriana, Malta.

Edited by: M.-H. Derron

Reviewed by: M. Jaboyedoff and another anonymous referee

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