Santa Marija Church,

Birkirkara, Malta.

Structural and geotechnical considerations in view of observed cracks

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Report of work carried out and proposed action

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1. Introduction

Santa Marija Church, Birkirkara is a prime example of the rich cultural and architectural heritage of the Maltese Islands. Unfortunately, this church has a long history of structural problems that have at times rendered it unserviceable and even led to its partial collapse in the mid-nineteenth century. At present, less than 20 years after completing the restoration process, a number of cracks are once again visible in the structure, and there are strong indications that these are developing further. In recent years, there have been a number of instances when pieces of mortar fell down from the vault of the main nave, luckily at times when the church was not being used.

The undersigned, as a qualified geotechnical engineer, has been commissioned to look into the causes of these problems, which are thought to be the result of appreciable settlement at foundation level. Geotechnical and structural analyses have been carried out to understand the existing situation and with the ultimate aim of identifying possible solutions of a more permanent nature.

2. Investigation

The development of cracks within the masonry walls and vaults of the church has been observed for a number of years, and has been first documented by Heritage Malta in 2006. This first report had suggested that ground conditions beneath the church could have caused these structural movements and recommended further studies in this regard.

In November 2009, a preliminary investigation was carried out during which three boreholes were drilled within and below the foundations of the church. Core was recovered from each of these three boreholes, and later inspected in the laboratory. A number of observations were made, namely that a relatively hard but very thin layer of rock exists below the church foundations, followed at depth by a thick layer of marl (a very weak rock or hard clay) of a whitish/greyish colour that has probably undergone some consolidation and compression over the lifetime of the church structure. Although these observations were made, the weak nature of the rock did not allow undisturbed samples to be taken for further testing in the laboratory.

A further two boreholes were drilled in September 2012, one below the west front of the church (the façade) and another one below the bell tower. These confirmed the findings of

the first three boreholes, but also allowed higher quality samples to be extracted and preserved for analysis in the laboratory. Parts of the retrieved borehole core were sealed to enable the moisture content to be preserved over a long time, for further study.

Figure 1 - Borehole core from investigation in September 2012

In October 2012, a trial pit was also excavated next to the façade of the church, down to a depth of 3.5m, thus allowing the upper hard crust and the underlying softer rock to be inspected at close range. A small section of the foundations of the church façade were also exposed in this trial pit. Several block samples of the weaker rock material were taken, sealed in plastic and wax and stored in a damp environment for subsequent analysis in the laboratory.

Figure 2 - Trial pit excavated below the West front, October 2012

3. Research

In 2013, two parallel studies were carried out, one concerning the structure of the church and another on the weak rock existing below foundation level. The latter is still ongoing, and now forms part of a research project being carried out jointly between the University of Malta and Bari Politecnico, Italy.

The first study consisted of a detailed survey of all the cracks visible inside the church, carried out by Ms. Bernice Darmanin in 2012-2013, then undergraduate student at the Faculty of the Built Environment at the University of Malta. Cracks were measured and recorded on drawings of the interior elevations, and classified in terms of severity, width and persistence. The current state of these cracks was compared to photographs taken some years ago when the problem was first identified by the architects and engineers at Heritage Malta. An attempt at understanding the deformational characteristics of the structure as a whole was also made during this study, and it was amply evident that the church has undergone severe distortion due to movement at foundation level. These patterns of distortion were analysed to obtain clues about the degree of settlement at the different locations around the church structure.

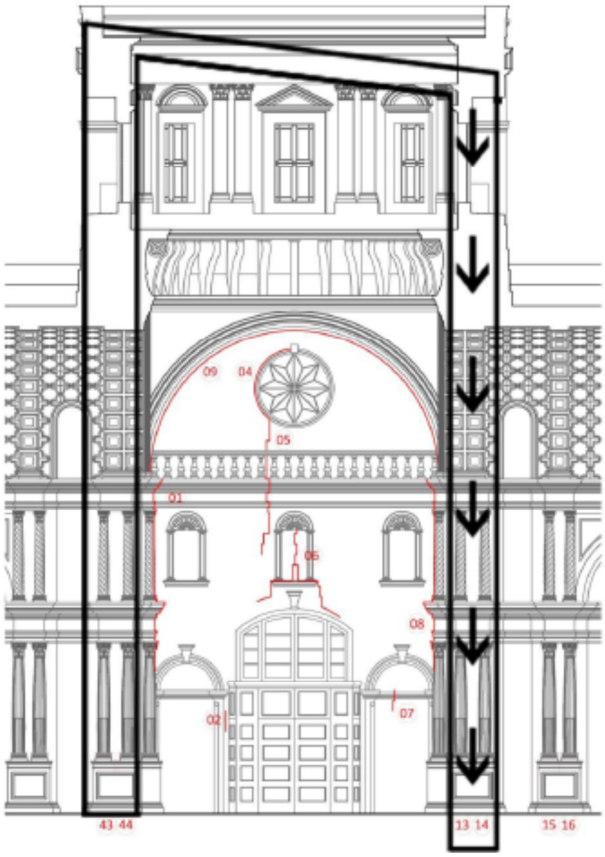

Figure 3 - One of several drawings showing crack patterns and perceived distortional mechanisms within the church structure

The findings of this study have clearly shown that the cracks visible within the church are not the result of a one-off event, but represent an ongoing process. Efforts have been made to monitor the structure more closely ever since this was realised, and recent surveys have confirmed the development of new cracks and the widening of existing ones.

Figure 4 - Some of the observed cracks within the church

The second study, being carried out by the undersigned, consisted in the classification and strength testing of the natural ground material found beneath the church. This is being carried out on the retrieved borehole core and on the block samples extracted from the trial pit. Detailed studies of the microstructure of this material have been carried out, using the scanning electron microscope at the University of Malta, and also by carrying out a series of laboratory tests both in Malta and in Italy. This study has now reached a phase where the strength, deformational and permeability characteristics of the material are being investigated. Initial results have already shone light on possible deformational mechanisms occurring within this material when it is loaded, and some hypotheses regarding the effect of this on the observed cracks have already been made.

Figure 5 – Triaxial cell and sheared specimen of rock from beneath the church (Bari Politecnico)

4. Monitoring system

The on-going structural movement and the development of cracks within the church is a matter of concern but it also provides important clues towards understanding the behavioural patterns of the church structure in relation to seasonal cyclic changes in environmental and ground conditions. So far, the cracks have been observed only by the naked eye, and therefore any data that exists is more of an qualitative rather than of a quantitative nature.

An electronic monitoring system has been designed (in conjunction with the Faculty of Engineering, University of Malta) that will be able to record very small movements across the cracks within the church, as well as other environmental parameters such as temperature and rainfall. This system, which is in the process of being installed, consists of a number of electronic measurement devices such as crack gauges and tilt meters connected to a datalogger which is housed in the church itself. The datalogger is periodically connected to a laptop computer such that the data collected over a specific time interval is downloaded for further analysis. This instrumentation will allow movements in the structure to be studied scientifically and to be interpreted in the light of the findings of the laboratory tests on the ground materials.

5. Conceptual model

The information from investigation, research and modelling is being used to construct a conceptual model of the church and the ground that it is built upon. This behavioural model is continuously being updated with new information that becomes available in the course of the ongoing research. Eventually all this information will be assembled in the form of a computer model that will allow predictions to be made and possible intervention techniques to be investigated. At present, quotations are being sought for the implementation of the upper (or structural) part of this model.

There is no unique or standard method though which the problems being observed within this church can be mitigated. Any kind of intervention within or below the church needs to be studied very carefully before works are implemented on site, since such works are likely to be very disruptive and costly. A computer model will therefore be very useful in assessing the efficacy of possible interventions and in refining the methods used to implement such interventions. Such models enable the construction process to be simulated stage by stage and enable investigation of the behaviour of the intervention many years after its completion.

6. Structural condition

There is growing concern that the structural condition of the church may pose some degree of risk to its users. Although the risk of collapse is considered remote, the observed structural movement may continue and may result in further spalling of masonry units and loosening of mortar infill. If this happens at ceiling level, any falling pieces could have substantial potential energy and may therefore cause slight injuries to people below. The probability of this happening during the limited time interval when the church is actually in use is small, but it cannot be ruled out completely. The possibility of introducing some form of protection needs to be considered and discussed in terms of the psychological effect this would have on churchgoers, who may overestimate the level of risk being mitigated.

7. Possible intervention

Considering the information compiled to date, it is yet premature to define the type of intervention that would eventually be required to stop any ongoing movement and to preserve the current state of this architectural monument. Further testing, analysis and

modelling needs to be carried out to establish the type and extent of the intervention required.

Possible interventions could include underpinning of the church foundations (by transferring loads to stronger strata at depth using piles), treatment of the ground, reinforcement of the structure, ties at foundation level and micropiling in less accessible areas below the dome supporting structures. In any case, such works would need to be carried out by specialist contractors who are experienced in carrying out such interventions on historic structures. Any form of intervention would also need to be studied from the point of view of conservation specialists and restorers. Above all, the impact of such works on the historical and architectural value of this Grade 1 listed building needs to be considered very carefully.

8. Funding

In view of the perceived need for intervention, and considering the typical complexity of works at the foundation level of a historic structure, ways and means of funding this conservation project need to be identified. This would facilitate a more structured approach towards the various project requirements and would enable more realistic timeframes to be drawn for all stages, including research, monitoring, analysis, statutory approval and intervention.

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