An Inspection of Three of Famagusta's Churches

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Built heritage, comprising structures such as bridges, tunnels, houses and so on, is a major investment of national resources in any country. This built heritage permanently accumulates damage due to deterioration of materials, repeated loading and exceptional events. As a result, conservation, repair and strengthening, are often necessary. Within this process, inspection and diagnosis techniques, play a major role, providing information and allowing the definition of adequate remedial measures. Structures of architectural heritage, by their very nature and history (material and assembly), present a number of challenges in conservation, diagnosis, analysis, monitoring and strengthening. These limit the application of modern legal codes and building standards. The recommended methodology adopts an iterative process between the tasks of data acquisition, structural behaviour, diagnosis and safety. The latter evaluation comes in two consecutive and related stages on the basis of which the effective need for, and extent of, treatment measures are determined. If these stages are performed incorrectly, the resulting decisions will be arbitrary: poor judgment may result in either conservative and therefore heavy-handed conservation measures or inadequate safety levels. Recently, the 'Recommendations for the Analysis, Conservation and Structural Restoration of Architectural Heritage' has been approved by ICOMOS, providing a sound basis of principles and guidelines.

In Famagusta three churches were selected for advanced, non-destructive inspection, namely dynamic and sonic testing, and preliminary diagnosis. These were: St. George of the Latins, St. George of the Greeks and The Carmelite Church.

Visual inspection:

<u>St. George of the Latins</u>

The Church of Saint George of the Latins is in a ruinous state of preservation. The church, however, still preserves its northern half, the lower section of the apse and part of its south side, which collectively offer enough evidence to demonstrate that it was an impressive example of Gothic architecture, with excellent masonry, compact proportions and rich stone carved decoration. The church is dated to the end of the 13th century and is a single-aisled building with four groin vaults which are supported by a grouping of three thin columns located in the north and south walls. A search of photographic archives indicates that the present condition of the church seems not to differ significantly from the condition around 1940. Severe deterioration of stones can be noted from drawings made in 1882, and several other stones have been replaced in the conservation work which took place around 1940. The present condition is characterized by: severe stone deterioration, loose stone elements, a highly corroded reinforced concrete lintel over the main door, inefficient buttresses due to stone deterioration, a crack / rotation of the tower, possibly due to a previous earthquake / foundation problems. These are illustrated in Figures 1 & 2.

Figure 1a-c: Details on current condition:

(a) severe stone deterioration;



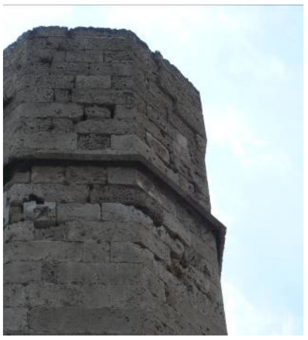
(b) loose stone elements;

(c) highly corroded reinforced concrete lintel in main door.

Figure 2 a-b: Details on current structural condition:

(a) mostly inefficient buttresses due to stone deterioration;

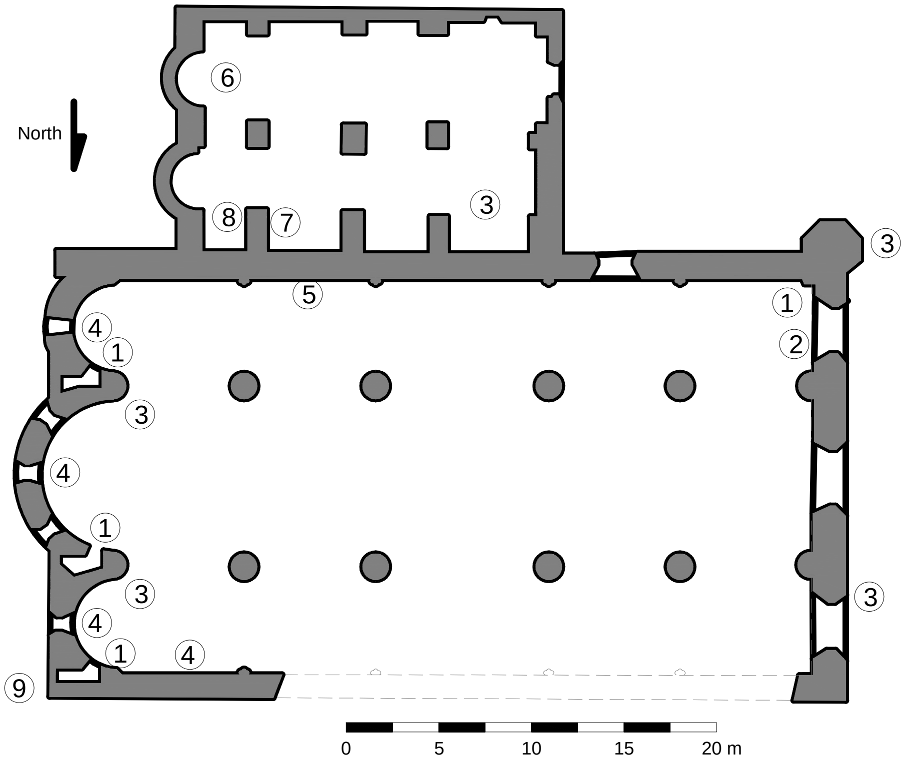
(b) a crack / rotation of the tower, possibly due to a previous earthquake / foundation problems.

St. George of the Greeks

The Church of Saint George of the Greeks is the largest Frankish Orthodox church in Cyprus measuring 37.5 × 20.5 m^2. It is dated with some certainty to the second half of the 14th century. The building is an interesting example of a Greek Orthodox church with French Gothic architectural features. Unfortunately, all that is left of the building is its east end, its central and side apses with their pointed domes, the nave's south wall and the lower part of the west end. The church is built with square sandstone blocks and it is three-aisled with two rows of columns. The dome sat on the square space formed by the second and the third column of each row, and the building has groin vaults. In the east the three aisles end in semi-circular apses. The roof had supporting pillars that bore the weight of the building's central aisle. The church's windows are simple and pointed whilst the entrances are adorned with carved relief decoration. Attached to the church's south side is the small, ruined church dedicated to Saint Symeon. The interior of the church was adorned with wall paintings but most of them were destroyed after the dome and the upper part of the building collapsed. Some fragments survive in the apses (depicting the figures of saints) but are exposed to the elements and are severely weathered. The present condition of the church seems not to differ significantly from its condition around 1940. Still, some aspects to be considered in any future conservation project are as follows (Figure 3).

Figure 3: Saint George of the Greeks and Saint Symeon

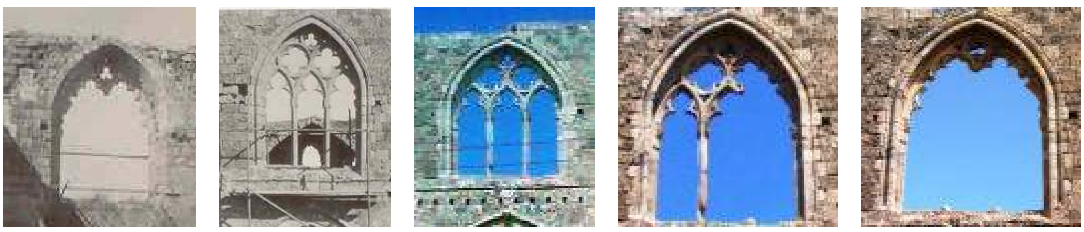


Recorded damage / possible remedial actions: (1) doors required to prevent free access; (2) moderate cracking present, (3) need to verify if removal / consolidation of masonry / stones are needed, (4) needs protection of frescoes and engravings, (5) needs consolidation of window tracery, (6) needs consolidation of vault (roof possibly needs works to protect from rainwater), (7) needs consolidation of arch, (8) severe biological contamination; (9) needs consolidation of flying arch.

The Carmelite Church

The church of St Mary of the Carmelites is situated in the northwest corner of Famagusta. Because the Carmelites originated from the Carmel Mountains of Syria, this area became known as the Syrian quarter of the city. It was built in the 14th century as the church of a monastery, and has a single nave of four bays and a three-sided apse. In the second bay, two small chapels were added. The roof had ribbed vaults, and the exterior walls were supported by buttresses. The tomb of Peter Thomas, who was the Pope’s representative and the Patriarch of Constantinople, who died in 1366, was in this church. The walls of the church were covered in frescoes, and some of those are still (just) visible. Outside the west door, you can also see the remains of sculptures above the entrance. Recently, the tracery added by the British above the main door around 1940 collapsed (Figure 4). The present condition of the church seems not to differ significantly from the condition around 1940 according to a visual comparison made with the images in the Mogabgab Archive.

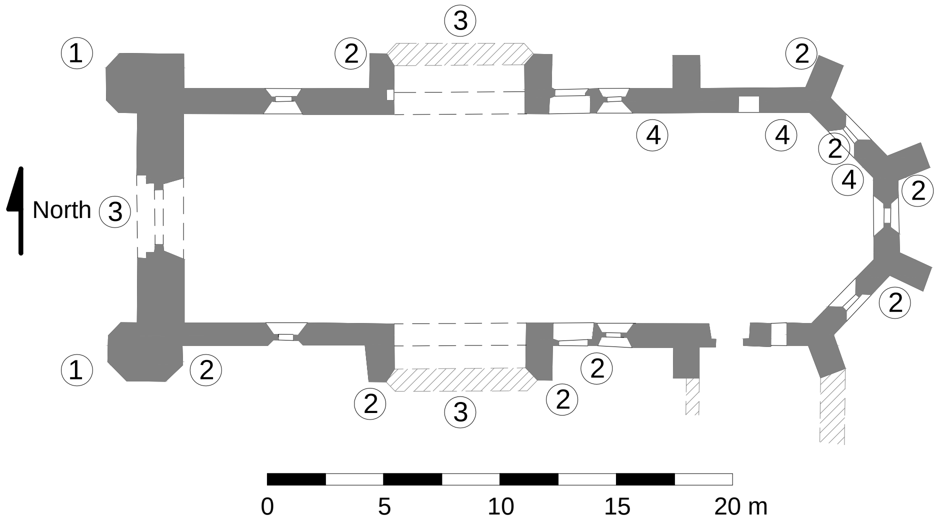
Figure 4: Window tracery above the main door.



1940 1941 2000 2006 2008

Some further aspects to be considered in any conservation projects are provided in (Figure 5).

Figure 5: *St. Mary of Carmel Church*



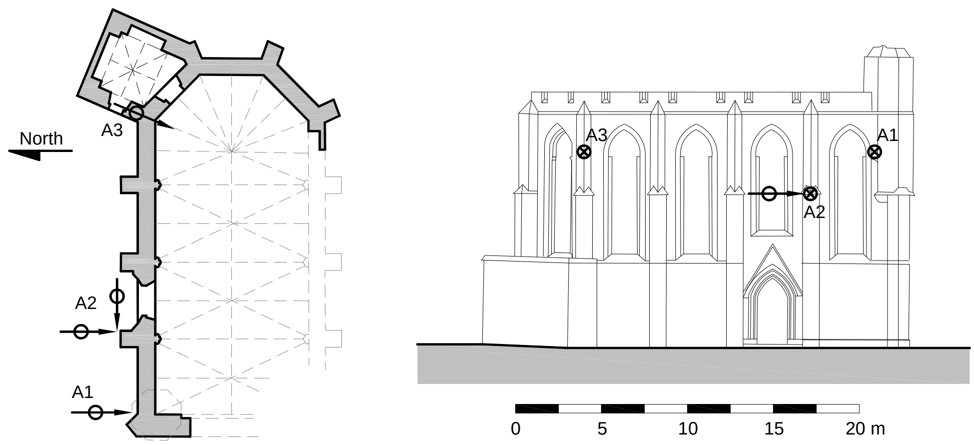
Recorded damage / possible remedial actions: (1) base of the towers exhibiting severe stone deterioration, (2) voids in the masonry, (3) possible elements to remove, (4) protection needed for frescoes and engravings.

In Situ Non-Destructive Testing

<u>Dynamic Tests</u>

Modal identification, or dynamic identification analysis, is a procedure that combines vibration testing techniques and analytical methods to determine modal (natural) parameters of structures. The modal parameters are frequencies, mode shapes, and damping coefficients. In other words, modal identification analysis is a diagnosis tool used to understand how a structure responds dynamically, e.g. to an earthquake, and to validate a computational representation of a structure. During the inspections on the historical constructions of Famagusta, dynamic identification tests were carried out in the same three churches: St George of the Latins, St. George of the Greeks and Carmelite church. Three accelerometers with 10 V/g sensitivity, able to measure 0.07 mg (g the gravity acceleration), were used to measure accelerations. The sensors were connected to a laptop by a data acquisition system with 24 bit resolution with a USB cable connection. Here, we present only the results for St. George of the Latins Church as an example of the work conducted throughout the city (Figure 6).

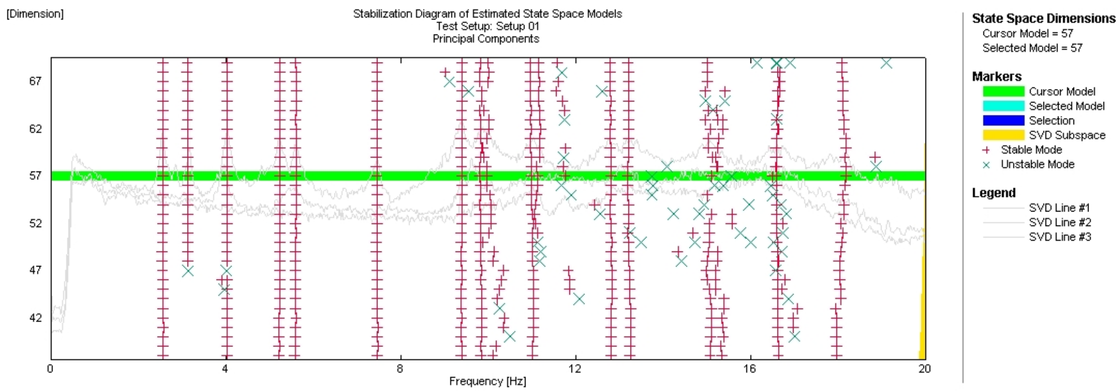
Figure 6: Test planning of St. George of the Latins church: top plan; and North façade.



The measurements were carried out in three points in the North façade, close to the top of three buttresses. The measuring points are indicated in the letter A (Fig 6). Images of the dynamic measurements can be seen (Fig 7 a-c) as can the stabilization diagram of the SSI method, where 17 stable columns can be observed, corresponding to 17 natural frequencies of the structure below 20 Hz (Fig 7 d). The standard deviation values for frequencies are very low, indicating that the estimation is accurate. The mode configurations are mainly out-of-plane modes, as expected due to the unconstrained walls of the church ruins.

Figure 7: Dynamic Testing at St. George of the Latins

(a) (b) (c)



(d)

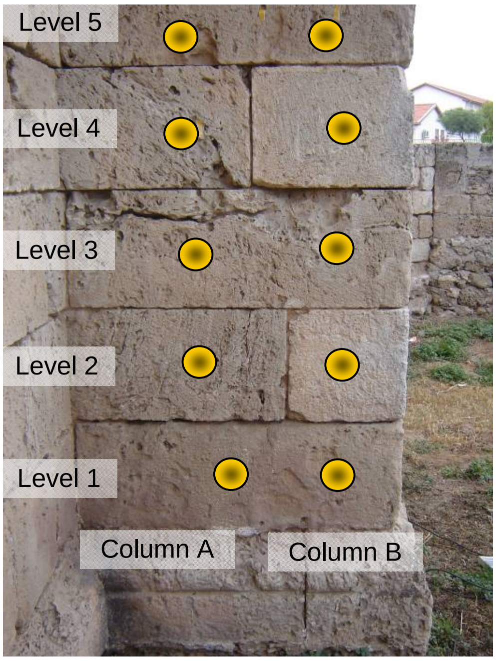
Dynamic testing at St. George of the Latins church: (a) lorry used to place the sensors in the structure; (b) accelerometers at position A1; (c) accelerometers at position A2; and (d) stabilization diagram.

Sonic Tests

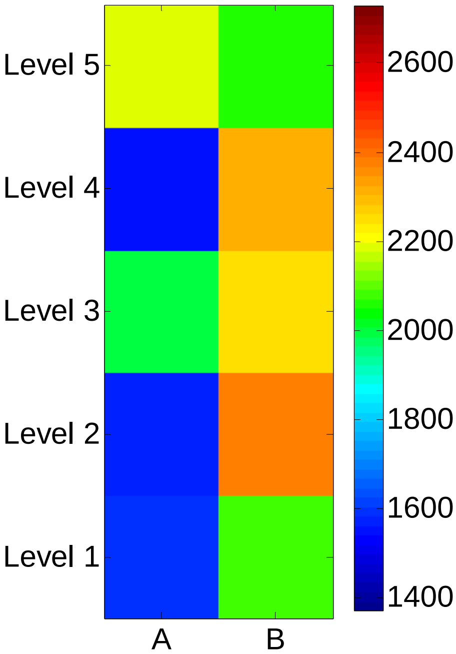
Sonic tests are based on the propagation properties of elastic waves on a solid. By knowing the distance between two points in the wall and by measuring the travel time, it is possible to calculate the sonic velocity (the velocity of the elastic waves). For sonic tests, two types of sensors are used, the hammer for impacts transmission and the receiver, which can be an accelerometer. The sensors are connected to a data acquisition system (DAQ) that acquires at a high sampling rate. When the geometry of a body, or structure, is known (e.g. the thickness of a wall or buttress), the time lag between the impact signal and the receiver signal allows the estimation of the sonic velocity inside the body. When materials with different densities, or voids, or cracks, exist inside another material, the sonic velocity decreases. If the body/structure is tested at several points, a sonic velocity map can be computed and it will qualitatively indicate the constitution of the wall and/or the presence of voids and cracks.

Sonic tests were only carried out at George of the Latins church on two buttresses, one on the North façade and one on the South façade. The aim was to evaluate the internal condition, mainly if there are internal voids, different density materials, or if repair works had occurred in the recent past. The tests were carried out with two accelerometers and one small hammer. The hammer was used to hit next to one accelerometer (the transmission sensor), while the other (the receiver) was placed in an opposite side of the stone or buttress. Two vertical alignments (A and B) and five horizontal alignments were tested (10 points per alignment). For the North buttress, Figure 8a presents the tested points. The results are illustrated in Figure 8b, and the sonic velocity ranges from 1400 to 2400 m/s. The average value for alignment A and B is 1597 and 2249 m/s, respectively. It is possible to see that the outer points of the buttress (alignment B) have a higher velocity than the inner points (alignment A). The results indicate that the stones in the outer alignment were probably replaced by new ones in the recent past, while the internal part of the buttresses are in worse condition. In the South buttress small differences were found between the velocity values. Ranging from 1400 to 2600 m/s, the average values for alignments A and B were 1923 and 1996 m/s, respectively. The values indicate that the internal condition of the buttress in the two alignments is similar, with similar distribution of voids.

Figure 8: Sonic Testing at St. George of the Latins



(a)



(b)

The full report, including the comprehensive results of all similar tests on St. George of the Greeks and St. Mary of Carmel, was submitted in August 2008 (Report 08-DEC/E-11).