Journal of Cultural Heritage 16 (2015) 526–535

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Original article

Using advanced NDT for historic buildings: Towards an integrated multidisciplinary health assessment strategy

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ARTICLE INFO

Article history:
Received 23 July 2014
Accepted 15 September 2014
Available online 11 October 2014

Keywords:
Health monitoring and assessment
Ground penetrating radar (GPR)
Thermal imaging
NDT
Historic building

ABSTRACT

This study aims to enhance the body of knowledge available in relation to the mechanical performance of historical structures and the assessment of the expected service life of such structures. The reliability of non-destructive techniques (NDT) is examined, in particular in connection with the technique's application to a historic Ottoman building located in Urla, Izmir, Turkey. NDT techniques are effective in the identification of such defects as cavities and water ingress hidden within a structure, in addition to providing information on material properties. This research is unique in utilizing NDT within a multidisciplinary assessment strategy to demonstrate its value within the field and will be of particular interest to structural engineers and architects.

1. Introduction

Historic buildings are significant symbols of any culture's heritage, and it is important to prioritize their protection against such destructive forces as flooding, freeze/thaw cycles, earthquake loads and general ageing. Many such buildings are available for public viewing, often providing financial and community rewards for the authorities responsible for them. The natural phenomena cited above are not alone in inflicting damage on the structural integrity of a building; the effects of live loads and their resultant vibrations are also capable of causing severe damage such as cracks which. In turn, these can weaken the structure and even lead to its eventual collapse. As some structural deterioration takes place beneath ground level, visual inspection cannot offer a comprehensive means of assessing a structure's state of repair, which makes the application of NDT highly desirable [1,2].

Simply put, a programme of structural assessment and monitoring with a view to informing ongoing maintenance is an essential aspect of preserving a culture's structural heritage. There is no set specification for assessing structural health, but, as a minimum, it must be acknowledged that it is necessary for such monitoring to be undertaken within a multidisciplinary environment of specialists and specialist equipment [3,4].

Whilst comprehensive building guidelines exist encompassing the building of new structures, the construction methods and materials for historic buildings would have varied greatly, depending chiefly upon the era in which the building work was undertaken. The building materials will largely consist of bricks, stones, adobe and mortar, with blocks size building style again varying depending upon the construction era.

As well as establishing the great importance of protecting these historical buildings from the various phenomena with the potential to jeopardise their structural safety, it is equally crucial within particular zones of the world, including Turkey, to evaluate seismic risk. However, undertaking a reliable risk assessment of a building is extremely challenging, involving qualitative and quantitative methods to ensure accurate judgements relating to maintenance [5]. Qualitative data can be retrieved by way of inspection of deterioration in combination with a defects and relevant literature review, but the collection of quantitative data is more problematic, involving of complex collection methods conducted by specialist. This makes the process costly, in terms of both time and money, thus necessitating that this process is carried out in a limited number of cases, and only when other methods have failed to produce the required information [6].

Various methods of NDT are available, including sonic/ultrasonic, electromagnetic and electrical and infrared thermography techniques, with each method capable of supplying particular information. In the past most tests using these methods needed to be conducted in the laboratory. However, continued innovations in non-laboratory NDT particularly GPR and infrared thermography,

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http://dx.doi.org/10.1016/j.culher.2014.09.010
1296-2074/

has led to a decline in cost, making them increasingly accessible [2,6,7].

Clark et al.'s [8] reports on the applications of the NDT inspection method of infrared thermography not only within the civil engineering discipline, but also in fields such as the medical industry, the publishing industry, and in locating and assessing buried mineshafts. Within civil engineering, NDT is typically used to appraise concrete and to locate deterioration and anomalies within structures.

It is recognised that, used in combination with more conventional methods of assessment, such as visual inspection, these methods can provide reliable assessments to inform decision-making. However, more recently, it has also been speculated that may be most effectively advanced by the use of two concrete assessment NDT techniques in conjunction, which has been shown to deliver high quality information in terms of both diagnostics and in an effort to reduce measurement noise. The techniques considered here are visual inspection, GPR and infrared thermography. The GPR system becomes unreliable in the presence of water and, to a reduced extent, porosity whereas ultrasound is unreliable in the presence of moisture and density, but can nevertheless assess the modulus of elasticity [9,10].

Although using two methods of assessment clearly has additional cost implications, this extra cost may be justified by the benefit gained in terms of heightened reliability in results. This study will therefore scrutinise this approach in an effort to endorse a multidisciplinary approach to the structural assessment of historic buildings using NDT.

The NDT of infrared thermography is a low/medium cost assessment method, which has the capability to monitor temperature in the long-term. Although simple for a trained its operator to use, its reliability depends on environmental conditions. As the infrared waves will not infiltrate a structure very deeply, the information gained from this technique is limited to the surface level. In comparison, GPR's greater penetration allows a superior volume of data collection [8,11–13]. However, as already stated, the two methods can complement one another in order to enhance the volume of collected data for comparison and validation purposes.

With historical structures often being subject to major defects, such as cracks, cavities, it is important to collect as much information as possible. This can be achieved by implementing an assessment program combining two complementary NDTs. In addition, it is not unusual for historical buildings to have limited or even a complete absence of surviving structural paperwork, as in the case with the Ottoman building in question. The lack of information, for example, in relation to support positioning, makes traditional inspection methods redundant in effective.

By using the inter-disciplinary method described, a comprehensive and reliable structural assessment of a historical building can be undertaken, so as to yield a comprehensive report on which to base decision making relating to structural maintenance, as well as locating hidden abnormalities such as cracks, delamination, moisture ingress and cavities.

2. Case study (Urla primary school)

The case study building is an Ottoman structure, which currently houses the Urla primary school (Fig. 1a). The building offers an ideal case study for this research, in view of the fact that minimal structural paperwork has survived. As such, the value of the multidisciplinary technique described can be assessed.

This sixteenth century building is situated in Urla, Izmir (Fig. 1b) and a south plan view can be seen on Fig. 2.

Fig. 1. a: view of the Urla primary school; b: location.

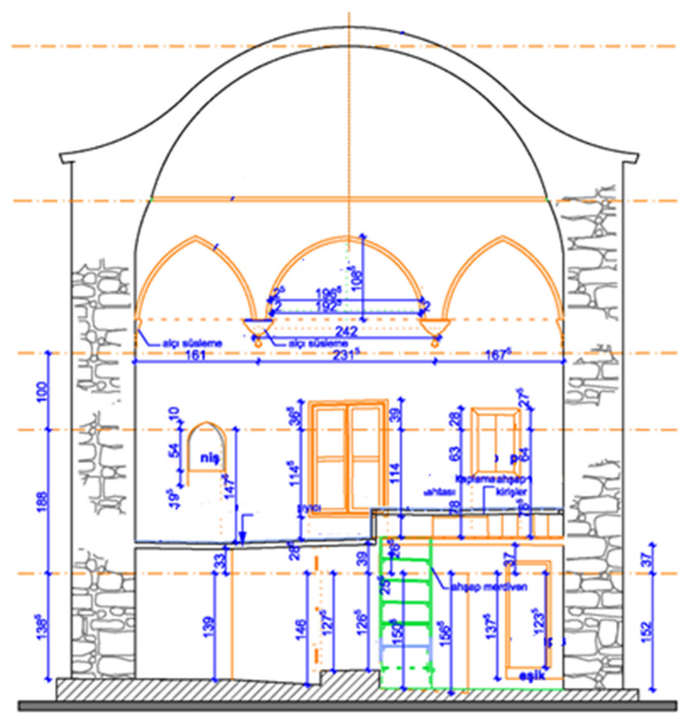

Fig. 2. South plan view of the Urla primary school AutoCAD drawing [34].

The building was subjected to structural petrographic analysis to determine the source of the rock and stone formations. The micritic limestone material used in the construction is relatively homogeneous, and these local limestone formations are commonly seen in Urla (Fig. 3).