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Original article

Simplified procedure for structural integrity's evaluation of monuments in constrained context: The case of a Buddhist Temple in Bagan (Myanmar)

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ABSTRACT

The research focuses exclusively on a simplified non-destructive testing procedure for first estimating structural integrity of monuments in constrained frame determined by emergency switchboard, need of rapidity, absence of economic support and complexity of the site and environment. The survey was inspired by the experimental outcomes obtained through easy-bring devices applied on a very old Buddhist Temple in Bagan (Myanmar) – whose area is UNESCO's site – built in the XII century. The ductile devices used for the investigation are the rebound hammer, the endoscopy and the ultra-sonic test. The procedure has been applied locally in the more significant masonry bearing parts of the temple. Particularly attention has been paid on the evaluation of the compression strength of brick and on the brick-mortar joints efficiency. The survey's approach is rapid, strictly in the frame of a preliminary and limited characterization, but significant for a first understanding of the masonry's integrity in absence of dedicated and elevated resources. The study outlines the reliability/limitations of the simplified and poor investigation's procedure in constrained boundary conditions, which is a very common situation in the anamnesis and diagnosis phases of monuments before restoration.

1. Introduction

Very often, the surveys aimed at assessing the state of conservation of monuments and historic constructions made by masonry or stone are constrained by lack of adequate funds, to the harsh environment or difficult boundary conditions and, conversely, the need to obtain quickly reliable results, least width a view to a first and rapid preliminary analysis. Added to this is that generally is not possible to withdraw the material to conduct destructive tests in laboratories, and that some monuments under investigation can be found in natural contexts not easily accessible.

The research fits into this context and through a particularly complex case study – the Phya-sa-shwegu Temple located in Bagan in Myanmar, built in the 12th century – proposes an experimental agile procedure to check in situ rapidly the structural integrity of the masonry walls, since that usually they represent the more significant bearing part.

In detail, the proposed research illustrates the combined use, yet little explored, of two non-destructive techniques for structural diagnosis which are easy-bring using as well as rebound hammer (RH) and ultra-sonic testing (UST). Despite the premise just described, in the investigated case proposed, it was also possible to use some bricks – fortunately already spontaneously fallen from the Temple due to the global decay – for indoor mechanical tests (IT).

The devices for non-destructive (ND) or micro-destructive (MD) investigation usually do not provide exact results, but allow to understand in depth the level of knowledge of the monument in its overall [1]. That is, for example, the understanding of the effective constructional details, the evaluation of the presence of voids in the masonry walls, the level of conservation and structural homogeneity of a load-bearing masonry and finally the level of compactness. These techniques are strictly necessary when it is impossible, even where prohibited, to intervene invasively, [2,3] or in presence of a fragile context as indicated in research [4], or a very complex one as that here investigated.

The ND tests are also used to assess the extent of damage to materials and structures strongly dated, to estimate the damage caused by natural hazard as well as earthquakes, fires, flood, extreme weather events. These devices are used particularly to investigate the state of knowledge of a historical buildings and monuments in view of restoration [5].

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The ND local techniques most commonly used are the sonic or ultrasonic tests, the geordar and thermography, concerning the understanding of the homogeneity and compactness of the masonry or stone walls. There is also the RH even if originally designed to indirectly determine the value of compressive strength especially in presence of concrete and mortar, if characterized by sufficient layer's thickness. Besides, the pachometer can be used to detect the presence of steel inside. The dynamic monitoring is then the only ND test – even if expensive and heavy in term of data elaboration – able to give a structural evaluation of the investigated construction in its overall.

Among the MD tests are reported the endoscopy and flat jacks. The first is for testing the internal stratigraphy of walls, vaults and pillars creating preliminarily a small hole – or into existing cracks – and by inserting a probe; the second, through small cuts in correspondence of the courses of mortar properly identified, it is useful for the indirectly determination of the stress of the masonry and its value of modulus of elasticity. In this frame, the combined use of endoscopy, RH and UST has been decided for their characteristic in term of easy bring, easy data elaboration and therefore to better and rapid focusing on the strength of brick and compactness of brick-mortar joints.

2. Aim of the research

The use of combined ND techniques for the structural integrity evaluation of monuments is the specific object of this research [6,7], especially in constrained frame. In this research guesswork, the expectation is less dedicated to the high quality of outcomes – values that we could get if derived through the more performing available in situ investigations – and more to the real possibility to set up a plan of combined ND test with rapid results useful for a first masonry integrity evaluation [8].

One of the topics proposed is the initial separate analysis of the data obtained through the rebound hammer (RH) and the ultrasonic test (UST), applying then a specific analysis on the overlapped results. The UST is less proper than the sonic test for masonry, but it was however used since that the very high thickness of the tested masonry wall and the dimension of the tested bricks [7]. The study shows also a comparison with indoor tests (IT) carried out on extracted bricks [6].

So, the aim of the research is related to the rapid-simplified approach in order to derive a first evaluation of the integrity of masonry in monument. The proposal of the simplified approach is due to the need to work in constrained context, which is a very common situation, in order to acquire a first quick and reliable judgment on the state of the masonry.

3. Typical monumental structures in Bagan's site

The case illustrated refers to a temple located at the UNESCO heritage site of Bagan in Myanmar, the largest area in the world in terms of concentration of Buddhist monuments belonging to types of Temple, Stupa and Pagoda. Inside, there are in fact about three thousand monuments built between the 11th and 13th centuries [9,10]. The classic type of Buddhist temple with vestibule – which also covers the temple investigated, albeit smaller – is shown in Fig. 1a). These temples – as that investigated – are characterized by the presence of a small advanced body, the vestibule, and then by the presence of the temple itself, which houses the Buddha.

4. The case study

The Phya-sa-shwegu temple appears very deteriorated due first to its spontaneous decay, as indicated in Fig. 1b. The temple shows a complex crack pattern as a consequence of the combined and interacted effects of the earthquake – that has hit in the 1975 the whole monumental area in Bagan – and the natural structural decay also incremented in consequence of some floods and differential settlements of the ground. The latter, aided by a too soft ground, have caused a further deterioration of the structural integrity of this temple. In term of dimensions, Fig. 2 indicates the maximum height of the temple equal to 10 m, the side of the temple is equal to 8 m, while the vestibule has 4.5 m side. The thickness of masonry wall of the perimeter of the temple is constant and equal to 138 cm, while for the central column that support the Buddha this value is equal to 175 cms (Fig. 2). An overall idea of the typical distribution of masses inside this temple and of the serious state of structural damage is presented in Fig. 3. In this figure, the characteristics of the monument, the level of conservation and the global/local decay are synthesized. The detail (a) indicates the high and wide level of damage in East Façade; the detail (b) is related to a big crack close to a window and around the corner between North-East facades; the detail (c) is related to a vertical main crack between temple and vestibule indicated both in the photo with the position's reference in the detail (c'); the two pictures in (d)-d') present the local decay of brick-mortar masonry respectively in South and North Facades; in detail, a case of residual plaster's presence is on the left while on the right is evident the absence of mortar's joints, as a consequence of the spontaneous material decay. Finally, through details (e) - e'), from the top to the bottom, the outcomes of the endoscopy investigations in two big cracks in North and East Facades are reported. An example of the high level of decay of the masonry is reported in Fig. 4, in the upper part, also with crack's width measures.

In overall terms, the temple is characterized by a large and widespread crack pattern that covers the inside as indicated in Fig. 4, in the lower part. One exception is the large central pillar built just below the central tower – which support the Buddha. The same cannot be said for the rather small pillars which divide the niches between the windows inside the temple. They are characterized by large cracks and serious material losses. Also, the vaults are cracked at the corners, most North and West side, which also coincide outside with the most damaged Facades shown in detail (b). The vestibule and the first entrance do not present structural damages. Fig. 4 shows also in detail a case of damaged masonry panel investigated.

The coverage appears in acceptable state of preservation with the exception of the pinnacles at the corners characterized by rigid out of plane displacements (Fig. 3a). Besides also, a spread loss of structural material and some areas with spontaneous local growth of vegetation have been detected.

5. In situ test program

The non-destructive investigations have been carried out with a rebound hammer (RH) type controls model C181N 6011 equipped with an equivalence scale to transform the value of rebound index to the value of compression strength, and the relative degree of dispersion of the obtained data [11].

The ultra-sonic test (UST) were performed with an apparatus type controls model E 46C, equipped with two probes and the possibility of connection to a dedicated software for more complex analysis in the time and frequency domain.

For the methodology to investigate the state of the walls, two masonry-panels in correspondence of each of the three external facades of the temple were preliminary identified. One panel was strongly damaged – see detail in Fig. 4 previously mentioned – and the other one undamaged or slightly affected by cracks.

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