GUIDELINES FOR IN-DEPTH CONDITION ASSSESSSMENT OF MONUMENTS AT BAGAN

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I INTRODUCTION

I-1 Project outline

Bagan Archaeological Area and Monuments Tentative List Site was the capital city of the first Myanmar Kingdom. It is a complex site in terms of its dimension of more than 13 by 8 km and also in terms of its large number of monuments exceeding 3000, many of which are still highly venerated by the local population, as well as, national and international pilgrims and tourists visiting the site. The proper management of such a heritage site entails a comprehensive set of protection, conservation and administration operations. All these operations require the allocation of human and economic resources that are currently still scarce in the country.
Following the successful World Heritage listing of the Pyu Ancient Cities in June 2014, the Myanmar government has singled out Bagan Archaeological Area and Monuments Tentative List site as its next priority for World Heritage nomination. Myanmar therefore requested support from UNESCO to provide technical assistance.

With a view to safeguarding Bagan within the World Heritage framework, it is important to improve the state of conservation of the monuments and to maintain the sites' authenticity and integrity in order to ensure that it is preserved for present and future generations. Bagan is vulnerable to a range of factors including disaster risk, weathering effects, and inappropriate conservation materials and techniques. In the face of a boom in visitor arrivals and accelerated development pressure it is not only important to improve the overall management of the site, but also to enhance the conservation practice and measures in Bagan in order to make the monuments resilient to the various factors that are affecting them.

In response to these needs, the project "Technical Assistance for the Conservation of Built Heritage in Bagan" was developed to improve the conservation of monuments in Bagan by demonstrating international conservation standards, as well as by improving national capacity in applied conservation techniques.

The project therefore focused on fundamental steps in the conservation process such as documentation of built heritage, rapid condition assessment and monitoring, as well as in-depth condition assessment. In the course of the project a series of trainings and hands-on working sessions were carried out that involved the technical staff of the Department of Archaeology and National Museum (DoA), as well as, national expert organizations such as the Association of Myanmar Architects (AMA) and the Myanmar Engineering Society (MES). The DoA staff and national experts worked alongside international experts and conducted result-oriented fieldwork in Bagan from which standard-setting documents for the future conservation of the site were produced.

The General Methodology for In-depth Condition Assessment of Bagan monuments is the result of a pilot assessment that was undertaken in several working sessions throughout 2015 at a selected monument in Bagan (No. 1249 Phya-sa-shwe-gu). The methodology was developed under the lead of Professor Masahiko Tomoda from the National Research Institute of Cultural Property Japan (NRICPT) who worked together with the DoA in Bagan, staff from the Association of Myanmar Architects and an international expert team consisting of Mara Landoni (conservation architect, University of Milan), Pierre Pichard (conservation architect, EFEO), Salvatore Russo (structural engineer, IUAV) and Saw Htwe Zaw (structural engineer, MES).

The specific objective of developing a methodology for In-depth Condition Assessment was to establish new standards for maintaining or recovering sound preservation condition of the Bagan monuments. However, conservation problems related to exterior as well as interior finishing of the monument, such as stucco or mural paintings, are out of scope of this project because another currently on-going project is dealing with these issues. This project is therefore focalizing mostly onto structural problems of the standing monuments.

I-2 Purpose of in-depth condition assessment

As means to assess structural soundness of the monuments in Bagan it was decided to set two steps, namely, 1) rapid condition assessment and 2) in-depth condition assessment. For the rapid condition assessment a standardized on-site inspection format was developed that is applicable for all types of monuments (named S-Card). In recognition of the fact that the monuments in Bagan show differences in terms of their structural characteristics and degradation phenomena, the approach to in-depth condition assessment could not be standardized to the same degree as the rapid condition assessment approach. Thus, a general methodology was developed to offer guiding principles and low-tech, as well as, high-tech options on how in-depth condition assessment and in situ structural diagnosis should be performed for Bagan monuments.

The definition of in-depth condition assessment is, briefly stated, to investigate causes and mechanisms of degradation in order to provide technical information for planning further conservation interventions.

The following GENERAL METHODOLOGY FOR ASSESSMENT section provides a standard working flow and concise implementation guidelines, including brief information of potentially available or recommended technologies for each step of in-depth condition assessment process.

The comprehensive analysis of the results obtained from various investigations and evaluations suggested in this document leads to the final structural condition assessment and formulation of recommendations for follow-up actions such as emergency preservative intervention, further research including continuous monitoring and long-term conservation planning.

It must be noted that these guidelines are based on wider and commonly used methodological approaches and techniques of in situ structural investigation as adopted by the international experts and scientific community in the field of conservation of cultural heritage. At the same time, however, the guidelines were prepared to suit the particular characteristics of Bagan monuments and respective degradation types that were observed. However, very unique types of structures or a rarely seen degradation phenomenon may require special manners of condition assessment, which may not appear in this document.

Further to this, the guidelines do not only propose high-tech investigative methods of international standards, but also include low-tech options for which the equipment and tools can be sourced locally when financial and technical resources are restricted as often the case in Myanmar.

Since the In-depth Condition Assessment is not a routine inspection like the Rapid Condition Assessment, it has to be specifically adapted to the condition of each monument that is being examined: for instance, there are cases where the foundation should be specifically assessed, in other cases it will be the crack pattern, or a wall out of plumb, etc.

Furthermore, it has to be noted that t**his process should be undertaken or supervised by experts with sufficient knowledge and experience in the relevant field of study, in particular architectural conservation and structural engineering.** It is highly recommended that the DoA seeks close collaboration with specialized agencies or external architects and engineers. The DoA could build on its already existing network of specialized institutions such as the Yangon Institute of Technology (YIT), Faculties of Engineering, the Association of Myanmar Architects (AMA) and the Myanmar Engineering Society (MES). It is advisable that the DoA systematically requests the technical advice from experts of such institutions before undertaking any in-depth investigation and before carrying out any structural intervention that goes beyond regular maintenance. In the future we can hope that the DoA will solve the problem of specialized staff shortage by recruiting a few engineers and architects with specific training on architectural conservation.

When an In-depth Condition Assessment is requested for a monument, the DoA can and should however independently undertake the preparatory steps, the first one consisting of a precise survey of the building, imperatively including the plans of all levels, cross sections and elevations. At the same time, the DoA should compile all available documents on the targeted monument, especially ancient photographs and any kind of record on previous interventions. As mentioned later on in this document, the DoA will also take care of the site preparation (clearing an access, eradication of vegetation on and around the monument, scaffolding and so forth).

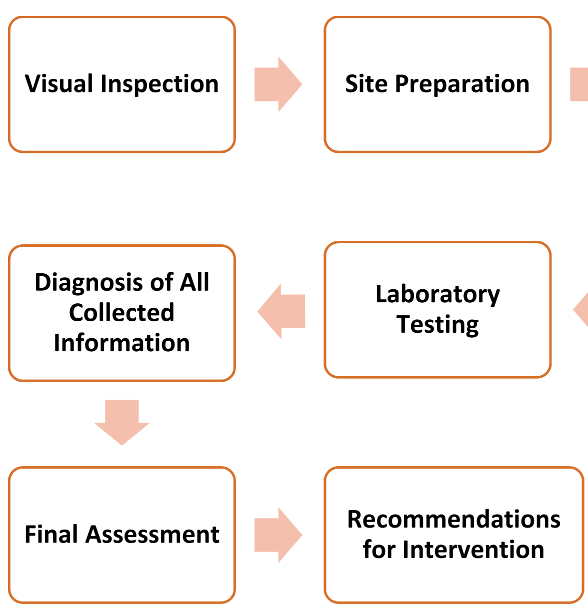
II. GENERAL METHODOLOGY FOR ASSESSMENT

II-1 Standard working flow

An ordinary overall process for conservation goes from 1) examination of symptoms, 2) making a diagnosis, 3) prescribing a medication, and then to 4) conducting a treatment before accomplishing recovery, just like a medical doctor is doing for the patient.

Among these steps of this whole process, in-depth condition assessment mainly deals with the stages one and two. However, as often the case, the diagnosis obtained by the assessment yields only a provisional prescription that is not sufficient for a full-fledged treatment. Full-fledged treatment for a patient corresponds to conservation and restoration works for a monument structure. Therefore, as a part of the planning process prior to the actual intervention further specific and detailed investigation may have to be performed. The goal of this in-depth condition assessment is to explain about the observed phenomena in general terms and to indicate what kind of investigation should be done in that next stage.

Standard working flow of in-depth condition assessment is illustrated below.



This document describes very concisely the objective (why), procedures (how, when and what), basic points of attention and generally applicable technologies for each step of this working flow. Among these steps, on-site investigation (II-6) and laboratory testing (II-7), in particular, require the selection of truly necessary items and methodologies of assessment in accordance with the specific character of the target structure as well as its condition. To carefully undertake this selection is critical for conducting an adequate and effective assessment.

It is always preferable to carry out on-site investigation by using non-destructive methodologies. However, depending on the investigation objective and characteristics of the target structure or due to given obstacles, it might happen that appropriate non-destructive methodologies are not available. In such cases, a micro-destructive methodology could become an option, however, the goal should be to obtain the maximum effect with minimum intervention by taking into account the balance between benefits of the information to be obtained and negative effect to the heritage value by the damage to be caused. The balancing of benefit and loss is similar to when planning a conservation intervention.

A condition assessment can be divided into two kinds of assessments, namely, qualitative assessments and quantitative assessments. Roughly speaking, the qualitative assessment comes first by understanding the type of degradation phenomenon and then grasping in numerical manner by quantitative assessment to what extent the phenomenon has progressed and affected the monument. Both qualitative and quantitative assessment methodologies are combined for analysis during the process of investigating the cause and mechanism behind the detected phenomenon.

In order to precisely assess the condition of a structure, it is necessary to understand in the first place what the structure consists of. Investigation on the structural composition of a building is also part of the in-depth condition assessment process. Brick masonry structures in Bagan show mainly two different kinds of bricks laying: surface sections and the intermediate sections. The former is always made with neatly piled bricks with thin joints, often being a contrast with the latter where bricks are disorderly laid with a lot of mud-mortar in between. Some structures even have hollow spaces exist inside of their thick walls, for example in the case of "blind corridors" that are found in some monastic monuments. These types of walls often have considerable impact on weight, stiffness and consequently behavior of the structure. Besides, in

Bagan it is often observed that large sections of the old masonry structures were replaced quite recently with new brick-mortar masonry.

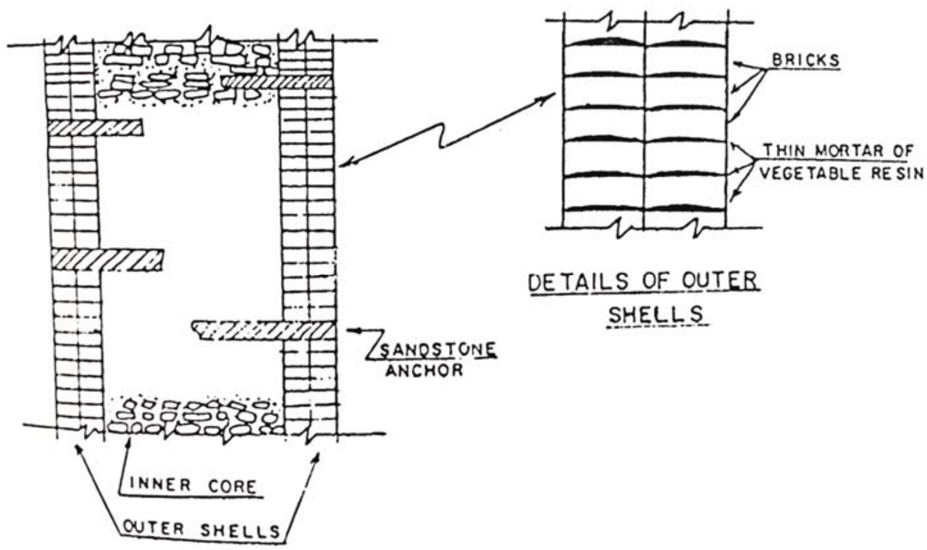


Fig. 1 Drawing of a section of typical wall showing the difference between surface sections ("outer shells") and intermediate sections ("inner core").

(*Source*: Department of Archaeology (Myanmar)/Institute of Asian Cultures (Sophia University Tokyo), *Study on Pagan*, 1989p.117)

II-2 Target of in-depth condition assessment

When, as a result of rapid condition assessment, a phenomenon is observed and identified as harmful for the structural stability and/or safety of visitors, it is necessary to identify the factors causing such phenomenon and shed light on the mechanism of degradation. This process is strategic in order to define measures for improvement of the condition with the ultimate objective of getting rid of the identified mechanism.

When degradation affects the structural stability of a building, the cause and effect of a degradation phenomenon do not always directly correspond to each other. Rather it is likely that there are different factors multiplying or influencing the effects of a certain cause, thereby giving rise to the next phenomenon that can accelerate the degradation even more. External factors such as short but torrential rain, a sudden earthquake or an exceptional wind may bring about rapid deterioration or collapse of limited parts of a monument or even of the entire structure. However, in most cases, it is more reasonable to think that a long–term progress of a complicated degradation process had already existed behind the scenes, which became apparent finally by external triggers. In other words, controlling such potentially hazardous factors and restraining or mitigating the progress of degradation within a certain extent is the best measure for protecting the monument from the potential collapse and consequently the irremediable damage.

Nevertheless, more than 3000 monuments exist in Bagan and the number further increases when taking into account the small structures and archaeological elements constituting each monument, as well as recently reconstructed monuments. Thus, it is nearly impossible to conduct a professional in-depth condition assessment and provide sufficient stabilizing measures for all of the monuments in Bagan.

In view of restrictions which Bagan is facing both in terms of lack of expertise and limited budget, it is important to prioritize the targets of in-depth condition assessment by consulting the results of the rapid condition assessment. The rapid condition assessment and regular monitoring of the monuments in Bagan makes it easier for the DoA to select monuments for in-depth condition assessment that are under higher risk or in a considerably advanced state of degradation. In contrast, structures that have already collapsed can be considered to be in a "structurally stable" state. Thus, the necessity or urgency to undertake in-depth condition assessment for such structures should generally be regarded low unless restoration works are planned to rebuild a specific collapsed structure.

It is not uncommon that degradation condition varies from one part to another even within a single building. In such case in-depth condition assessment could be performed in a limited area where degradation phenomena are particularly observed. Notwithstanding, since structural degradation is a complex process as stated above and even if only local destruction is clearly observed overall structural could often be involved, it is desirable to narrow down the target area of investigation after thoroughly observing situation of the structure as a whole.

II-3 Overall visual inspection

In preparation of the technical investigations with special devices, the overall condition of the target structure must be inspected by a survey. The survey usually involves a broad appraisal which produces a relatively fast scan of the condition of the building. It is generally used where a quick result is required, funding is limited, and/or the numbers of artifacts or the dimension of the site is large: the case of Bagan. The inspection should be carried out by technical personnel. A survey can be conducted by the application of a prepared field card (S-card) or by visual condition assessment in which the occupants or appraisers provide feedback, particularly about the state of conservation, the vulnerability and the risk of the artifacts. The weakness of these approaches is that it is not easy to understand the cause of decay; without in-depth condition assessment methodology, it is not possible to have a complete overview of the monuments' problematic situation.

The aim of visual condition assessment or application of the S-card is first to define the level of urgency-emergency of intervention, second to define the priorities of interventions in order to prevent severe damage phenomena (as collapse or instability), so as to remove its causes.

In an evaluation of potential losses it is also not possible to exclude a set of estimations that can be given for each monument. In other words, these judgments can be influenced by different intrinsic aspects: rarity of the monument as historical evidence, extraordinary artistic quality, economical value of the loss in case of decay and consequent need of conservation actions, usefulness of the building (functions hosted), role of the monument in a context of touristic valorization and depending on specific political and cultural aims.

In Bagan the visual observation has been standardized by the rapid condition assessment card (S-Card). In the context of the in-depth assessment, this process further aims to perceive the situation in a holistic manner from a professional viewpoint, narrow down the possible candidates of the degradation factors, and examine to decide what investigation should be performed in the in-depth condition assessment, together with its general target area. (See Appendix for full card.)

STRUCTURE RAPID CONDITION ASSESSMENT CARD BAGAN, REPUBLIC OF THE UNION OF MYANMAR Version8 03/16	Monument Number/Name:

1. IDENTIFICATION OF MONUMENT & DETAILS OF INSPECTION

Name of Monument	Monument Number	Main Entrance Orientation

Type of Monument

☐ Temple ☐ Stupa ☐ Monastery ☐ Underground Structure ☐ Archaeological Element / Surrounding Structure (e.g. wall, gate) ☐ Other (specify)

Location Description (include locality number if known)

Location GPS Coordinates (Lat/Long) and Elevation (Above Sea Level)

Topography

☐ Plain ☐ Elevated ground ☐ Slope ☐ Depression ☐ Hilltop ☐ Valley ☐ Other (specify)

Previous Intervention	Previous Investigation and Report
☐ Conservation (structural) ☐ Conservation (chemical) ☐ Re-plastered/whitewashed ☐ Restoration ☐ Reconstruction ☐ Excavation ☐ Other (specify) Date of intervention (if known) and Description:	☐ Documentation ☐ Field Observation ☐ Survey ☐ Technical Report ☐ Other (specify) Description:
Inspector (s) Name	**Inspector (s)' Institution**
Inspection Date	**Weather Condition on Inspection Date**
	☐ Raining ☐ Not Raining

Type of Inspection

☐ Regular Inspection ☐ Emergency Condition Assessment ☐ Rainy Season Inspection

Remarks (in case of emergency assessment):

3. LEVEL OF PRIORITY AND RECOMMENDED ACTIONS

Monument Grading	Value factors (taken into account for prioritization)
☐ Grade I ☐ Grade II ☐ Grade III ☐ No Grade	
Overall Severity Magnitude of Observed Degradations	**Overall Extent of Observed Degradations**
☐ High ☐ Medium ☐ Low	☐ Partial to Total ☐ Partial ☐ Limited

Overall Condition Rating – Current (based on severity and magnitude of overall degradations)

☐ Very Bad ☐ Bad ☐ Poor ☐ Fair ☐ Good

Remarks:

Overall Risk Rating

☐ Very High ☐ High ☐ Medium ☐ Low ☐ Very Low

Remarks:

Immediate Action(s) Needed

☐ Vegetation clearance ☐ Waterproofing ☐ Drainage improvement ☐ Partial masonry repair
☐ Locking gate and fencing ☐ Other (specify):

Action(s) Needed

☐ Emergency action needed ☐ In depth condition assessment ☐ Mural and decorated surfaces assessment ☐ Further rese
☐ Minor Conservation ☐ Relocate development proposal ☐ Improve previous restoration
☐ No action needed (stable condition) ☐ Other (specify):

Fig. 2 First page and prioritization section of the Structure Rapid Condition Assessment Card for Bagan Monuments (S-Card)

(*Source*: ©UNESCO, 2015)

This is an indispensable step for whatever the target structure is in its style, scale and degradation condition. And the different technical investigations to be performed afterwards can be said, in most cases, as the process to verify the hypothesis that is built by the visual observation on the cause and mechanism of the damage and degradation.

Not different from the case of rapid condition assessment, the observation should start from the external inspection, in which the overall condition of the structure is checked by looking at from a distance in every direction first and then particular section is checked by a closer look. It is basically same for the interior where floor, wall and the lower side of roof should be observed systematically without any oversight. At this moment, some section cannot be observed closely without scaffolding, and a use of a binocular could be an effective means in such case.

The important points to be checked are, at first, the portions showing significant damage or degradation. The corner of external walls where the stress concentrates and the meeting point of different structural elements such as the main body and the entrance hall or the tower and the roof can easily cause cracks. Leakage of the rain water into the interior or a growth of vegetation is often related to existence of cracks, and therefore these phenomena can be important clues to find the cracks. Moreover, if the wall or the roof is partly collapsed, observation is possible at such a broken section to inspect not only the internal structural composition but also damage or degradation condition of inside, which makes the portion to be a priority area of inspection.

Another important point to be checked in the overall observation is a manner of displacement and the consequent deformation, such as leaning of the tower or the exterior wall, and unevenness at the bottom of a wall or around a base, in particular. Observing and recording the presence or absence of such problems, together with their direction or location if any, target area of the measurement is identified.

Occurrence of cracks is in most case linked to the structural displacements. The visual observation needs to focus on such linkage between a phenomenon and another. For example, irregular curvatures and deformations of a vault, leaning of a wall and unevenness of a base are observed together in a proximity area, it must be rather possible that these phenomena are interrelated than that each phenomenon occurred independently.

Among Bagan monuments many temples and monasteries are structures in a symmetrical shape, and stupas commonly have same shape in four directions. Notwithstanding a symmetrical shape of the structure, if the degradation pattern differs from one face to another or the structure leans to one direction, such asymmetry may suggest any difference in the ground strength, load distribution, external conditions or others. Examining through this kind of observation what investigation should be performed, simultaneously with selection of the particular target area to be investigated, survey plan for the in-depth condition assessment should be developed.

II-4 Site preparation

This includes all on-site work that should be done in preparation of carrying out the subsequent investigations. Specifically, securing access and ensuring safety for investigation, clearing vegetation, and setting up scaffolding are usually required.

Securing access and safe movement

In order to survey the entire structure, approach to the object area must be secured. For an in-depth condition assessment use of a very large or heavy device is usually not necessary, but it is still desirable to have a vehicle's access to the direct vicinity of the building in view of the transportation of scaffolding and other materials. Even if approached by foot there may be the need for measures to provide access, for example, for drainage when the surrounding area of the building is flooded. Inside of the building there may also be a blocked section due to fallen building members. If any investigation is needed in an area beyond the blocked section, the access must be secured. However, removal of the fallen members without much consideration can be dangerous and cause further collapse or instability. Therefore, sufficient care must be taken.

Clearance of vegetation

The clearance of major vegetation growth is necessary not only to improve the access, but also to remove any obstacles that could hinder visual observation, photographing or measurements. Depending on the size of the building, a radius of 3-5 meters surrounding the foot of the external walls should be cleared at least. In some cases, the cutting of a neighboring tree to the building may also be required. Plants are growing on the ground, walls and a roof of the building, which becomes an accelerating factor of the structural degradation. In that sense clearance of vegetation inside and outside of the building is an action directly contributing to the improvement of the preservation environment. However, it is very difficult to physically remove the roots that have penetrated deep into the brick joints and have grown there, which may induce structural instability or increase of the rain water infiltration. It is better to cut the roots at the wall or floor surface, and dispose the remaining parts with a safe biocide.

Scaffolding

After completing the photographing to record the present condition and basic measuring works, scaffolding for investigation is set up on the building. It is not always necessary to build it around the entire building, but in view of reducing the cost it is preferable to limit the area with scaffolding to where investigation is required. Even for a large building, setting up high scaffolding should be avoided except it is absolutely necessity. Any investigation that is impossible without high scaffolding should rather be carried out later as a part of the conservation project. Regarding the type of scaffolding, single-pipe scaffolding has an advantage in terms of stability and, bamboo scaffolding that is commonly used in Bagan can meet the basic requirements. In terms of safety, single row scaffolding is not sufficient and double row scaffolding with footboards should be used especially for carrying out a surveys using different devices such as rebound hammer, ultra-sonic device or similar. For the use of scaffolding inside the building with stable floor, a rolling tower can be useful. Depending on the objective and area of the investigation, the appropriate method should be selected. In any case, it should be noted that it is preferable to build the scaffolding without any direct contact or anchorage to the building.

Temporary support

In situations such as the significant leaning of a wall, advanced cracks on the roof or its partial collapse particularly in the investigation area, measures for temporary support should be installed for ensuring safety of the workers. If fallen bricks are scattered on the floor there is a danger that a larger collapse will occur even if this stage of the conservation process usually does not involve any investigation methods that cause large vibration,. It is recommended to use a helmet during the work and to minimize entry to such an area.. When a large-scale supporting structure is required, it should be made, not as a part of the preparation works, but rather as part of the conservation project after sufficient planning based on the result of investigation. Finally, the area of the investigation for the condition assessment explained here should be limited to what is accessible without safety concerns.

Fig. 3 A Bagan monument prepared for in-depth condition assessment. The access was secured and vegetation cleared in a radius of about 3-5 meters before setting up the scaffolding around building parts that need investigation.

(*Source*: ©UNESCO/M. Tomoda)

II-5 Basic documentation

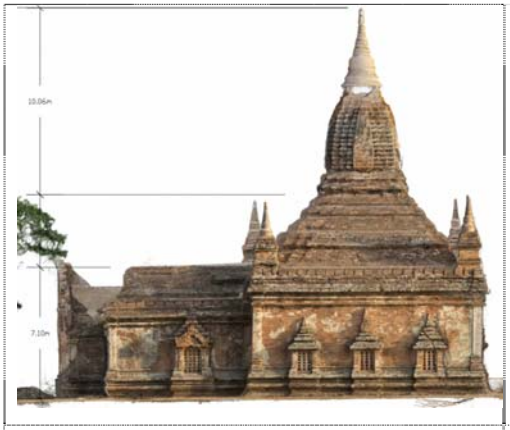
Prior to performing specific technical investigations, the target building must be documented in detail. The types of drawings needed as well as their required accuracy may depend on what sort of investigation is expected afterwards. The minimum requirements, however, are basic scaled drawings for every floor plan, four side elevations, two cross sections, interior elevations of all rooms, ceiling plans and a roof plan.

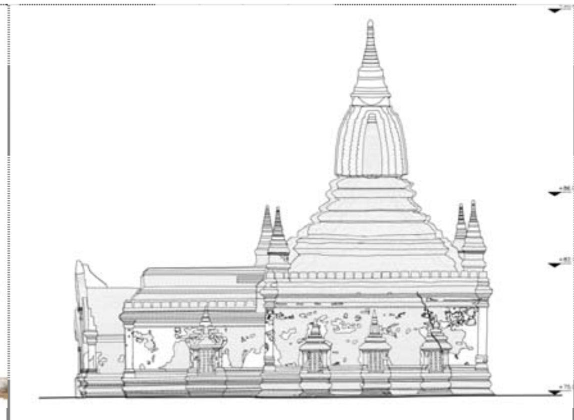
It is sometimes necessary to record the information not only about the building itself but also about its surrounding ground profile or topography. This is especially needed when there is a substantial difference of height in the surrounding ground or the surrounding topography may be a factor that affects the degradation or deformation mechanism of the building. In such cases, a schematic topographical map should be produced by conducting a simple land survey.

Photographing is also necessary to document the actual condition. The basic requirements for the exterior view are four side elevations and an overall view from an oblique direction, and two different side views of major spaces for the interior. Additional locations should be selected in accordance with shape and scale of the building. Photo documentation of the area of degradation is made as part of the investigation works, which needs to devise a way to make manner or extent of the degradation visible, by putting horizontal or vertical lines or scales in the images (see further below ‘documentation of crack patterns’).

The detailed graphic documentation of the existing state of conservation is useful not only for defining a pre-diagnosis, but also for subsequent steps such as the planning of conservation interventions, and the comparison of the monument post-intervention with its previous state. Great attention should be given to materials, to their arrangement, to their working process, and to their decay.

Diverse methods are used for surveying and documenting, from the traditional measuring by hands to the state-of-art laser surveying. The selection of the method to be applied should be made in consideration of the characteristics of the building and the availability of technology as well as devices. For the base drawings for the in-depth condition assessment the minimum requirement is to have precise horizontality and verticality in addition to the accuracy in scale. For Bagan monuments which include a great number of large-scale buildings and tower-shape structures like stupas, manual measuring is not enough and surveying by using a level and a theodolite machines should be the minimum requirement. Moreover, it is impossible without using a 3D laser scanning to record precisely the deformation of walls and roofs.





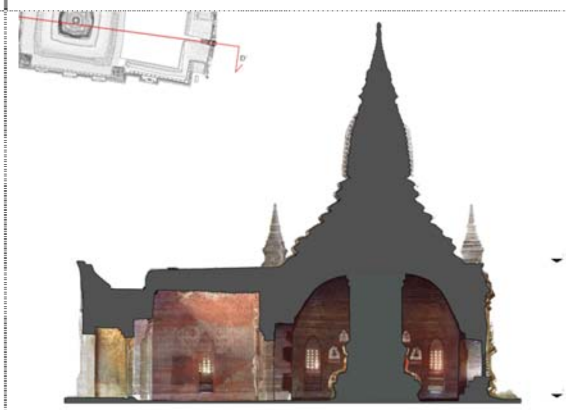


Fig. 4 (upper-left)
Fig. 5 (upper-right)
Fig. 6 (below-right)

Examples of reference drawings for in-depth condition assessment of a Bagan monument. The minimum of required reference drawings for in-depth condition assessment are basic scaled drawings for every floor plan, four side elevations, two cross sections, interior elevations of all rooms, ceiling plans and a roof plan.

(*Source*: ©UNESCO/Carleton Immersive Media Studio)

II-6 On-site investigation

This chapter contains an overview of the technical investigations for the structural condition assessment that can be performed in situ of the target building. The description includes objective of the investigation, implementation procedures and analysis of the obtained results. A variety of methodologies can be used for each kind of investigation. Therefore, the selection of the appropriate methodology should be made by an expert in the specific field in accordance with the objective and characteristic of each technique. It should be noted that this document only explains the most widely employed methodologies. The evolution of new technologies is so rapid that not every specialized technology is worth being mentioned in this document. This document introduces both, the globally used latest technologies and methods as well as the basic ones that may not require any special devices and advanced knowledge. Taking into account financial as well as human resource constraints that Bagan is facing, this document has been put together to offer high-tech and low-tech methods for in-depth condition assessment that can be combined in multiple ways for the specific investigations.

1) Observation, recording and survey

Based on the result of the overall visual inspection, close observation and detailed recording of the identified problematic sections should be performed. In specifically, the affected area, condition and degree of each degradation phenomenon should be recorded on the prepared drawings and should also be recorded by taking the photographs. During the observation, particular attention should be paid to the relationship between different phenomena. For example, the relation between cracks on the exterior and interior surfaces of a wall, the distribution of cracks and displacement or leaning patterns of walls. The interrelationships between the different degradation phenomena can be revealing for determining the exact causes and effects of degradation.

Crack pattern

Observation and recording of a single crack and crack patterns should include key information such as location, direction, width, length, depth, as well as manner and degree of gap between both sides of the crack. The most critical factors for judging the impact on structural stability of the overall building are whether a crack penetrates the whole thickness of the wall body or the roof, whether the crack continues from the bottom to the top part of the structure, as well as how wide the crack is. Continuation in a wide area of a penetrating crack means that both sides of the crack are already in a structurally discontinuous state. When taking the photographs from the starting point up to the end point of each crack they should be taken continually, and also by putting a scale such as a measure tape across the crack to show its width. Generally speaking, a vertical crack is often related to the overloaded bearing capacity, the unequal leaning or subsidence of the structure or the horizontal stress of the out of the plane direction. A diagonal crack is usually caused by horizontal stress of the in-plane direction such as the effect of earthquakes or progressive increment in the time of a lateral static load.

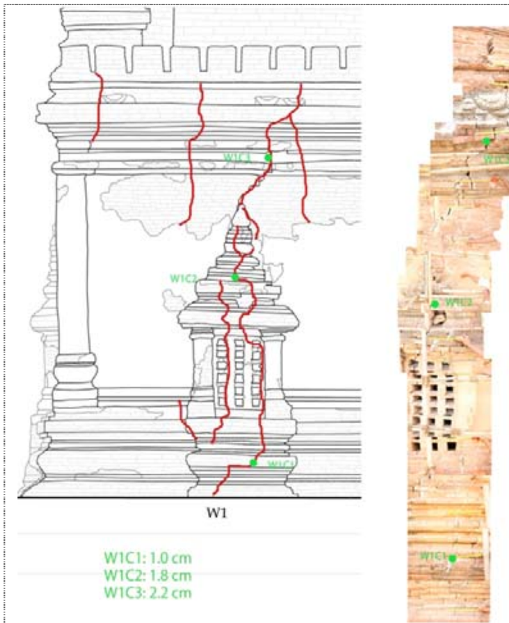
North (Exterior) Crack Pattern									
No.	Location	Starting Point	Ending Point	Type	Wide	Length	Direction	Speculatry	Short Remar
N1	Left window of the main building	from the first pediment	to the base of the platform of the temple	Crack	N1C1: 0.4 cm N1C2: 0.9 cm N1C3: 0.5 cm	975 cm	Slightly Diagonal	_	Brick Decay side of wall
N2	Middle window of the main building	from the first pediment	to the base	Crack	N2C1: 0.5 cm N2C2: 2.3 cm N2C3: 1.3 cm	1127 cm	Vertical	_	Continuous through to t window
N3	Right window of the main building	from the first pediment	to the base	Discontinue	N3C1: 0.5 cm N3C2: 6.0 cm N3C3: 2.5cm N3C4: 5.0 cm	988 cm	Slightly Diagonal	_	Very Big Cra is moving ou
N4	Lower Right, upper left form window	from pediment	to upper base	Crack	N4C1: 0.5 cm N4C2: 1.8 cm	520 cm	Vertical	_	_
West (Exterior) Crack Pattern									
W1	Left Side	from the first pediment	to the base	Discontinue	W1C1: 1.0 cm W1C2: 1.8 cm W1C3: 2.2 cm	940 cm	Slightly Diagonal	_	with 3 crack crushing wir (moving out
W2	Middle	from the first pediment	to the base	Discontinue	W2C1: 1.5 cm W2C2: 2.5 cm W2C3: 3.5 cm	880 cm	Vertical	_	1 Big Crack v minor cracks diagonal mo cushing win
W3	Right side	from the first pediment	to near base of window	Discontinue	W3C1: 1.3 cm W3C2: 2.0 cm W3C3: 3.0 cm	650 cm	Vertical	_	Not only hor carcking but moving outv
South (Exterior) Crack Pattern									
S1	Left Side	from pediment	to the side of the window	Crack	S1C1: 1.0 cm S1C2: 0.8 cm S1C3: 1.3 cm	240 cm	Vertical	_	with 3 crack crushing wir (moving out
S2	Middle	from pediment	to the base	Crack	S2C1: 0.2 cm S2C2: 0.3 cm S2C3: 1.0 cm	380 cm + 350 cm	Vertical	_	2 main Crack
S3	Right side	from pediment	to the side of the window	Crack	S3C1: 1.0 cm S3C2: 1.5 cm S3C3: 0.7 cm	340 cm	Slightly Diagonal	_	_

Table 1 Sample of a table for recording key information about individual cracks.

(*Source*: ©UNESCO/C.Rellensmann)

Fig. 7 First the cracks are marked with chalk and then documented in detail using a scale bar in the photo in order to provide information about the width of the crack.

(*Source*: ©UNESCO/C.Rellensmann)



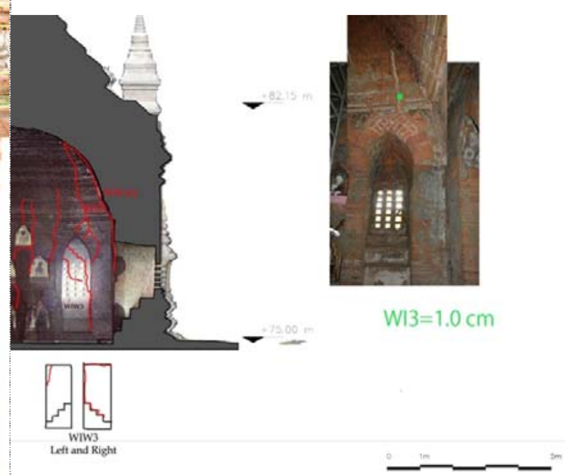


Fig. 8 (left), **Fig. 9** (right) The digital documentation of two corresponding cracks on the exterior and interior wall of a monument.

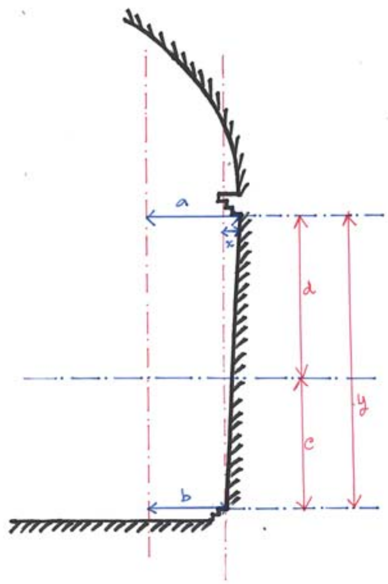
(*Source*: ©UNESCO/Association of Myanmar Architects)

Displacement pattern

Condition of the displacement must be understood in a quantitative manner. The cases of leaning and subsidence should be measured for the entire the structure or at least for those areas where particularly significant displacement is observed. Concerning the historical building, which is often in absence of specific drawings, it is difficult to know how accurately the original construction was made, and it is almost impossible to verify the achieved accuracy in particular for the verticality and horizontality. Nevertheless, it is natural to think that the constructor intended to make the walls vertical and the lines of cornice or moldings horizontal. Therefore, obvious difference in the measured results could suggest possibility of structural displacement, and this is further possible in case that the both exterior and interior faces or bottom and top lines of a wall show discrepancy of similar tendency. On the other hand, for example, such situation that the exterior side of the wall has an outward leaning and the indoor side is vertical or with different leaning degree may suggest also a cavity or a non-homogeneous empty zone produced inside the wall. In such case, the condition should be confirmed more precisely by the next step of investigation for example through an observation of the core of the wall by using an endoscope. The measured data on the amount of displacement should be recorded and maintained in preparation for later comparison in the continuous monitoring.

Measurement of displacement

As for the methodology to measure the displacement, when 3D data obtained by a laser scanner is available the exact quantity of displacement of any point can be extracted directly from this data. If alternative low-tech methods were employed to produce drawings of the structure, the measurement has to be made again by selecting appropriate points to be measured. When control points are established at both outside and inside of the building and a total station is available, a coordinate of each measurement point can be measured directly. When there is not a standard coordinate, first setting a base line along a wall the horizontal distances are measured directly from the baseline at the top and the bottom - the bottom end of the top cornice and the upper end of the base moldings - of the wall. This can be realized by using a measuring tape and a plumb bob, and setting a horizontal base line on the wall surface the distances from here to the top and bottom ends of the wall are also measured.



x = a – b = outward displacement

y = c + d = wall height

x/y = leaning angle

Fig. 10 Sketch indicating the measurements that have to be taken for assessing displacement.

(*Source*: Prof. Masahiko Tomoda, National Research Institute for Cultural Properties Japan (NRICPT) 2016)

Only an automatic level and a theodolite are required devices to do this, but even more primitive method of water leveling can set a horizontal standard.

If available, the use of wireless inclinometer installed on the top of each structure with remote data acquisition system is preferable and suggested generally for slender monuments such as those commonly seen in Bagan.

Others

All other problems like materials damage, location or area of each degradation pattern should be recorded on the drawings for stratigraphic analysis, and the representative images of the situation should be photographed.

2) Chemical /biological/environmental evaluation

This process of in-depth condition assessment is intended to deal mainly with structural problems. However, chemical or biological deterioration of materials constituting the structure may also affect the structural strength either directly or indirectly. The problem of the mechanical strength of the material is further described in Section 4) on structural material analysis.

Example of chemical deterioration

The most representative chemical deterioration to occur to brick or stone materials is salt weathering. This is a weathering process caused by repeated absorption and evaporation of water that bring soluble salts such as calcium and sodium contained in a mineral to flow and accumulate near the surface of the material, which leads not only to a change in chemical composition of the material but often also lowers its mechanical strength. The salts appear on the material surface as white deposits, and crystalized salts in the cavities of the material cause pressure that leads to breakage of the material. Salt weathering occurs often at the bottom of a wall that is adjacent to the ground or on the retaining wall of a terrace that has a soil filling causing continuous supply of water. Occurrence of the damage at the bottom of a wall becomes a great risk to the overall structural stability.

On-site test of chemical deterioration

It is difficult to measure the change of a material's chemical quality on site and in a non-destructive manner, but for stone material, for example, measuring the degree of weathering by analyzing the difference of magnetic susceptibility and a range of other methodologies can be applied. In addition to this, increase of the porosity of the surface appears is determined through a change of the water absorption rate. Thus, a surface water absorption test can be conducted by fixing a circular-shaped water absorption cup with a tubular pipette that can estimate the degree of weathering. This method, however, is not suitable for the measurement of a large surface area. Precise diagnosis of the chemical deterioration requires laboratory testing by collecting samples.

Biological deterioration

Microorganisms growing on the surface of a building not only disturb the aesthetic value but sometimes also accelerate the weathering of the material. Although the mechanism is still not clear how mosses, algae and lichens directly break the object material, a certain correlation is observed between the growth of bryophytes and the degree of the surface weathering. Therefore, it can be said at least that the growth area is in an environmental condition with higher risk of weathering. When efflorescence and growth of bryophytes are observed in a limited area on the lower surface of roof, leakage of the rain water should be suspected.

Growth of microorganisms also provides favorable conditions by keeping water or soil particles for the growth of higher plants. Roots of plants penetrate into such tiny interstices like brick joints, grow bigger inside to widen the gap, making infiltration of the rain water easier, and accelerating breakage and deformation of the entire structure. That is why the growth of vegetation must be observed carefully to examine the measures to improve the situation.

Environmental monitoring

In case surface weathering is significantly advanced on a particular side or area of the building, either outside or inside, it can be assumed that this is caused by some external condition that occurs particularly on that particular section of the building. Environmental monitoring can help to define the external condition that is leading to the observed weathering. Setting up an automatic weather station, which usually measures temperature, humidity, direction and velocity of wind, as well as rainfall and solar radiation, can do this. The periodic observation data is recorded with a data logger. Alternatively, a simple temperature and humidity sensor that contains a data logger can be used for the monitoring of interior environment. In any case, it is necessary to continue the monitoring for one year at the minimum in order to grasp the seasonal change of the environment conditions.

3) Geological and geotechnical evaluation

Uneven settlement significantly affects the stability of a structure thereby influencing the distribution as well as evolution of the structural damage. If such phenomenon is noticed during the visual observation and measurement survey, information must be collected about the characteristics of the ground as well as formation and shape of the building foundation. This should be done through both analysis of available documents and investigations on site.

Excavation survey

It is difficult without dismantling the superstructure to investigate the overall shape and composition of the buildings' foundation. If the target area of the investigation is limited, the most secure way is to make a direct observation by exposing the foundation with an excavation survey. The excavation and examination of foundation can also be supported with endoscopy. However, much attention should be paid to conducting an excavation in the area of advanced degradation as it might lead to the risk of further instability of the building. In case some part of the building was already collapsed, this section could potentially be a secure and safe location for the excavation survey.

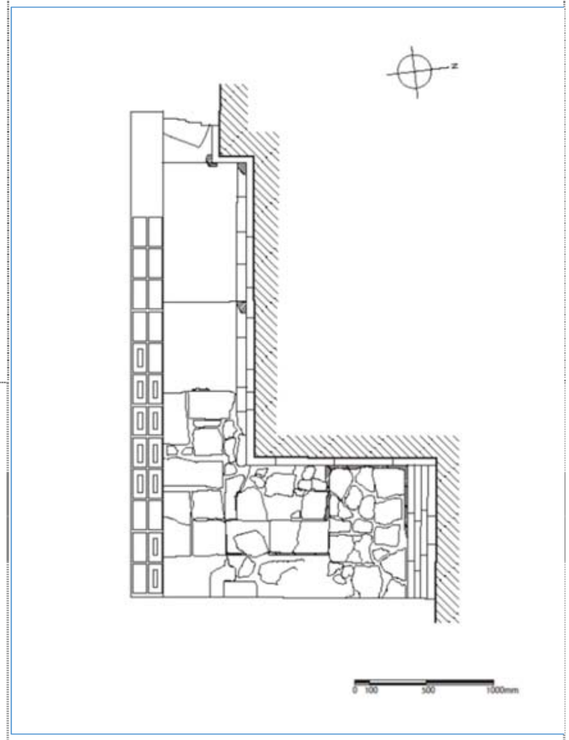


Fig. 11 (upper-left), **Fig. 12** (below-left), **Fig. 13** (right) Detailed documentation of a surface excavation of a Bagan monument to investigate the type of foundation.

(*Source*: Prof. Masahiko Tomoda, National Research Institute of Cultural Properties Japan (NRICPT), 2015)

Boring test

Auger boring is used for investigating the soil composition and stratigraphy of the foundation layers or the ground of a relatively shallow range. A hand auger to turn with human power cannot penetrate the layers containing hard soil, stones or brick fragments around the building, which is generally used only after reaching a homogeneous earth layer by removing the surface layers. For a relatively soft layer of earth, a hand auger can go about 5 to 8 meters deep starting from the surface. Mechanical boring for Bagan monuments, however, should be limited to the preparative stage of a full-scale restoration project. Rotary boring without causing percussion can be used for extracting a columnar core sample including of the brick foundation structure.

Ground strength investigation

A standard penetration test using a boring pit and the Swedish sounding test are the most widely applied methods for investigating the ground strength. For the Swedish sounding test an iron rod with a screw point on the top is put vertically on the ground and amount of sinking by putting weights as well as number of rotation for constant penetration length are measured to calculate the ground strength. When the excavation is made to the bottom of the foundation, bearing force of the supporting ground can be directly measured by a loading test, though it requires a reaction force such as from a heavy machine.

Measuring of underground water movement

In the area of high underground level or significant seasonal change of the level, it should be assessed how this impacts the building structure. Direct measurement of the underground water level is possible at a well or a boring pit. For the continuous monitoring of the seasonal change, an automatic water level measuring apparatus is generally used, however, if not available it can also be substituted by asking some local people to record the level manually on a regular basis.

4) Structural material analysis

It is necessary to know the mechanical parameters (strength and the modulus of elasticity) of materials, not only to properly analyze the structural performance of the investigated structure, but also to judge the homogeneity or heterogeneity of the mechanical parameters in the construction. This is in fact an indispensable process for understanding the distribution of strength in the masonry of the monument and for making the right choices for its restoration strategy.

For a certain method to measure materials strength, for example, it is necessary to do a breaking test of the collected samples in the laboratory, however, it is desirable to minimize the collection of samples from the cultural heritage building.

Collection of samples for laboratory testing

Generally, a mechanical core drill is used for extracting samples from the wall body of a brick masonry structure. However, for ancient structures like in Bagan it is impossible to extract an integrated core sample of brick and mortar due to the relatively low bonding strength of mud mortar used for the construction. Therefore, the only feasible way to obtain such integrated sample might be by cutting out a massive block from the broken section of the building or a fallen piece that is already separated from the structure.

For an individual sample of brick, rather than extracting by mechanical drilling, a fallen piece could be collected and used as a test sample. In either case, the collection place must be recorded on a drawing and a picture of the situation before the collection must be taken. Collection must be made only after writing on the piece a sample number with chalk, and having photographed it again. In case of using such fallen material as a sample, the most important thing is to assure that it certainly belongs to the building concerned. Particularly when found outside the building, the particular brick materials might originate from somewhere else. Even within the same building, the deterioration degree of the brick varies from one section to another. Therefore, priority should be given to the collection of brick samples which provenance can be estimated with a higher degree of certainty. Every time a sample is collected its original location must be recorded in the drawing, by taking photographs and by writing a memo about basis of the estimation and degree of certainty. In the case of brick samples it is furthermore recommended to make an in situ tests of the strength of the individual samples by using a rebound hammer (see description on application further below) before taking the samples to the laboratory in Yangon for testing.

Generally, it is preferable to also reproduce a masonry sample in the laboratory. The masonry sample should be made of original bricks samples and a new mortar that is as similar as possible to the original mortar used in Bagan and analyzed in situ. The more similar the "fake" masonry sample is to its original the more reliable the results of the laboratory tests will be in terms of recreating the actual mechanical behavior of the masonry of the monument of origin.

Brick samples for testing from Phya-sa-shwe-gu, temple no.1249

#	No.	location	Dimension (LxWxD in mm)	Origin	Remarks	Suitabililty for testing (sclerometre)
1	S-1	1st window	220x105x45	unknown	hole in the middle	11-17-19-22-24
2	S-2		285x190x50	unknown	new brick	22-22-21
3	S-3	2nd window	180x160x50	unknown	old brick	12-12-11
4	S-4	2nd window	180x160x50	unknown	old brick	20-20-[12-16-18]
5	S-5	2nd window	350x210x65	unknown	old brick	26-28-24
6	S-6	2nd window	160x160x45	unknown	old brick	12-15-13-13
7	S-7	3rd window	160x110x55	unknown	old brick	unable to conclude the test, because brick broke during test
8	W-1	4th window	200x100x55	unknown	new brick [hole in the middle]	21-23-14-18
9	W-2	4th window	155x120x55	from vault above window	old brick	16-15-16
10	W-3	4th window	210x165x60	from vault above window	old brick [broken, W3a and W3b]	18-12-20
11	W-4	5th window	220x180x60	unknown	old brick	19-19-21
12	N-1	7th window	220x175x60	unknown	old brick	20-16-14-18
13	N-2	9th window	180x135x55	unknown	old brick	22-30-28
14	N-3	9th window	300x195x70	unknown	old brick	18-[23-28-24-22-23]
15	N-4	9th window	210x165x70	unknown	old brick [original edging?; cut inside]	24-25-20-21
16	N-5	9th window	490x330x200	unknown	sculpture piece	(X)
17	eN-1	entrance hall north window	325x200x60	unknown	full brick [old brick]	24-28-28
18	eS-1	entrance hall south window	250x200x60	unknown	old brick	24-28-28
19	eS-2	southern stair way	200x250x55	from upper part of ceiling		unable to test
20	TN-1	terrace	430x225x65	unknown	old brick	21-18-28-23
21	TN-2	terrace	180x225x65	unknown	old brick	12-12-12
22	TN-3	terrace	230x200x60	unknown	old brick	from 45 [22-20-18]
23	TN-4	terrace	220x100x70	unknown	new brick [hole in the middle]	16-16-22

Table 2 A table showing recording key information about the collected brick samples such as number, location, origin, and suitability for testing.

(*Source*: ©UNESCO, 2015)

Fig. 14 A brick being measured and marked according to its suspected place of origin (S=south).

(*Source*: ©UNESCO/C.Rellensmann)

Fig. 15 Bricks are neatly arranged and their suitability for laboratory testing is tested by applying the rebound hammer before packing them carefully to be taken to the laboratory in Yangon. Any kind of vibration that could impact the strength of the bricks should be avoided during transport.

(*Source*: ©UNESCO/C.Rellensmann)

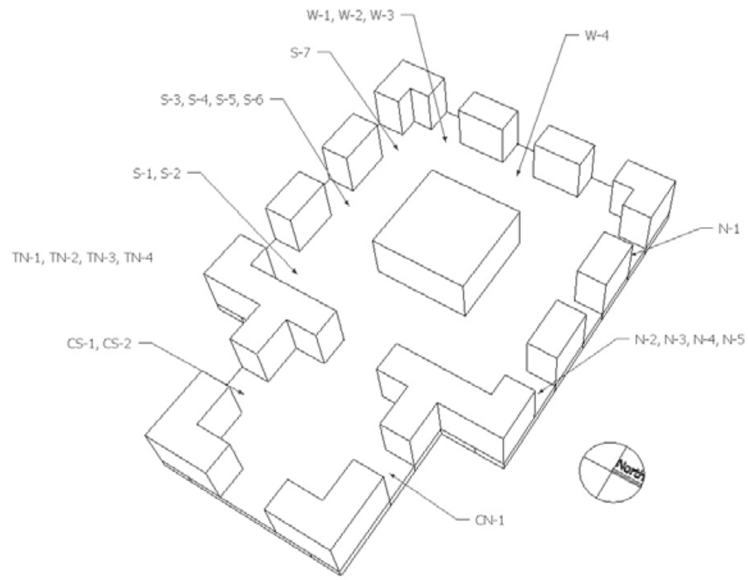


Fig. 16 Drawing indicating the provenance of brick samples within the target monument (TN1-4 are from the north side of the roof terrace). This information is important for later analysis of laboratory results in relation to the target monument's stability.

(*Source*: Myanmar Engineering Society, Hlaing University, Yangon, Myanmar, 2015)

On-site testing of mechanical parameters of materials

Methodologies to test on site mechanical strength of the material are described below. It has to be noted, however, that each methodology can give only an indirect estimation of the strength and in order to know the real value a destructive strength test in the laboratory is required. That is why it is necessary to compare both results from a non-destructive measurement on site and a destructive test in the laboratory on the same piece of sample. Adequate number of in situ tests holds a key to the reliability of the results. This is the reason why at least three times of test should be applied for each brick or brick-mortar joint. This advice should be adopted for all types of in situ investigation.

Rebound hammer test

This testing method uses a device that is generally called "Schmidt Hammer" and originally used for concrete material. In the methodology frame of a rapid and simplified approach in constrained condition – as proposed here – this device can also be used for brick given that the application is repeated several times for the same brick and that indoor mechanical tests are undertaken to complement this data. Hardness of the material surface is measured by the rebound index when the test hammer hits the object at a defined energy. The rebound index value has a correlation with a uniaxial compressive strength of the material, which can be estimated by using a conversion chart corresponding to the device. In order to confirm and ensure that the results obtained with the rebound hammer are reliable, it is recommended to run destructive tests on extracted samples of brick in parallel to obtain compression strength values. For using this method the object material needs to have enough strength to be able to tolerate a hit by the metal hammer, and particular attention should be paid to its application to the cultural heritage or a deteriorated object with lowered strength to avoid the risk of damage. An equotip hardness tester is also used for the similar purpose.

The following is a brief description of the application procedure: a) In situ recording of the mean value index (3-5 tests); b) Find in the conversion diagram the closest value in its X axis to the value indicated by the rebound hammer; c) Intercept a function curve for the hammer's orientation during the test; d) Read, on the Y axis left, the correspondent value in term of strength; e) Read, on the Y axis right, the dispersion value; f) Then, note the strength and dispersion values. The way in which this kind of results could be used is first to understand the level of homogeneity in defining the strategy of the structural intervention; this specific aspect is developed in sub sections II-8 and II-9.

Fig. 17 A rebound hammer and its component parts.

(*Source*: http://www.startimes.com/?t=30313257)

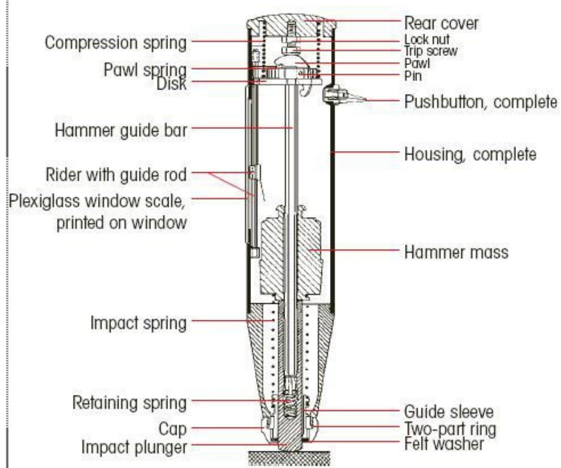
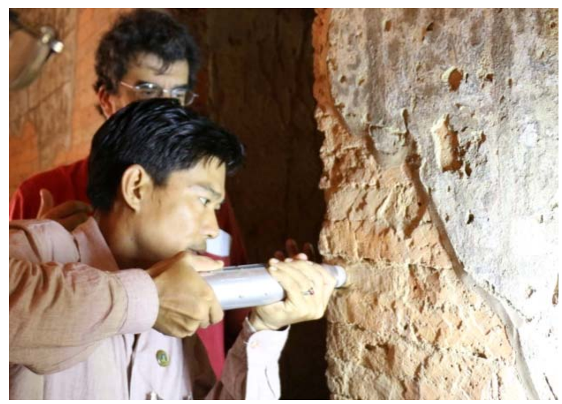


Fig. 18 A DoA staff member using a rebound hammer. The plunger should be pushed in a 90-degree angle against the testing surface. When the plunger makes the impact on the surface the locking button has to be pressed. Afterwards, the rebound value can be read from the scale.

(*Source*: ©UNESCO/C.Rellensmann)



Needle penetration test

Needle penetration test is the generally used strength testing method, which is applicable for relatively soft materials. Inserting a thin metal needle into the object sample, the inserted length and the needed load are measured to calculate a needle penetration incline (N/mm).This value has a correlation with a uniaxial compressive strength, and thus the material strength can be estimated. This method cannot be applied to such hard material that does not allow the needle to penetrate. Also, as it leaves a hole of about one millimeter diameter on the sample, this is not included in the category of non-destructive methodology. It is effective for strength measurement of soft bricks or mortar materials.

Resistograph in presence of timber structural parts

This is equipment for determining the real strength of a wood material. This equipment is a specific mechanical device similar to the penetrometer for mortar and widely used for in-situ testing. It gives an effective mechanical performance by using a localized intensive drilling whose resistance correlated with the density of the wood is then automatically translated into the mechanical value. It is recommended to repeat a sufficient number of this measuring procedure from statistic point of view and also in consideration with non-uniformity due to the wood-fibers orientation.

Fig. 19 The use of resistograph on timber during the building investigation.

(*Source*: *https://commons.wikimedia.org/wiki/File*:*Resistograph_(Foto).jpg*)

Ultra-sonic test

The above two testing methods (rebound-hammer test and needle penetration test) are both for indirectly estimating the strength of the object brick or mortar independently, which are effective to know the deterioration condition of each material but not efficient enough to measure the overall strength and degree of compactness of the structure even if making the measuring points multiple. For the purpose of measuring the compactness of masonry – and specifically the efficiency between brick-mortar – for such relatively large area, the methods by using an electromagnetic wave or the ultrasonic wave are applied. The ultra-sonic method is widely used method by measuring the velocity of sonic wave inside concrete. In the frame of a rapid and simplified method of assessment, the ultrasonic device could be also used for massive masonry walls. This is possible by measuring the time needed for transmission of the ultra-sonic wave through the inside of materials from the terminal of the dispatch side to the reception terminal. The ultra-sonic wave transmits throughout both brick and mortar materials, which makes it possible to relatively detect lowering of the compactness including the discontinuity at the boundary areas. However, the measuring is not possible if any boundary of complete discontinuity such as a penetrated crack exists within the target area. The procedure is very easy first by measuring in situ the distance between the two sensors and then reading the time value needed for the sonic wave to connect the sensors, which will be directly shown by the device. Then dividing the distance by the time, the answer will be the velocity that can be used as index of the reduced or sound quality of compactness. The way in which this kind of results could be used is first to understand the level of homogeneity in defining the strategy of the structural intervention; this specific aspect is further explained in subsections II-8 and II-9. The ultra-sonic method is also used for the measuring of the depth of a tiny crack observed on the brick surface.

Fig. 20 Test panel of a Bagan monument with individually numbered bricks. For each brick the rebound-hammer test is applied at least three times and noted down in the field notes. The ultra-sonic test is also undertaken in order to determine the overall compactness of the entire brick masonry panel. (*Source*: ©UNESCO/AMA/DoA)

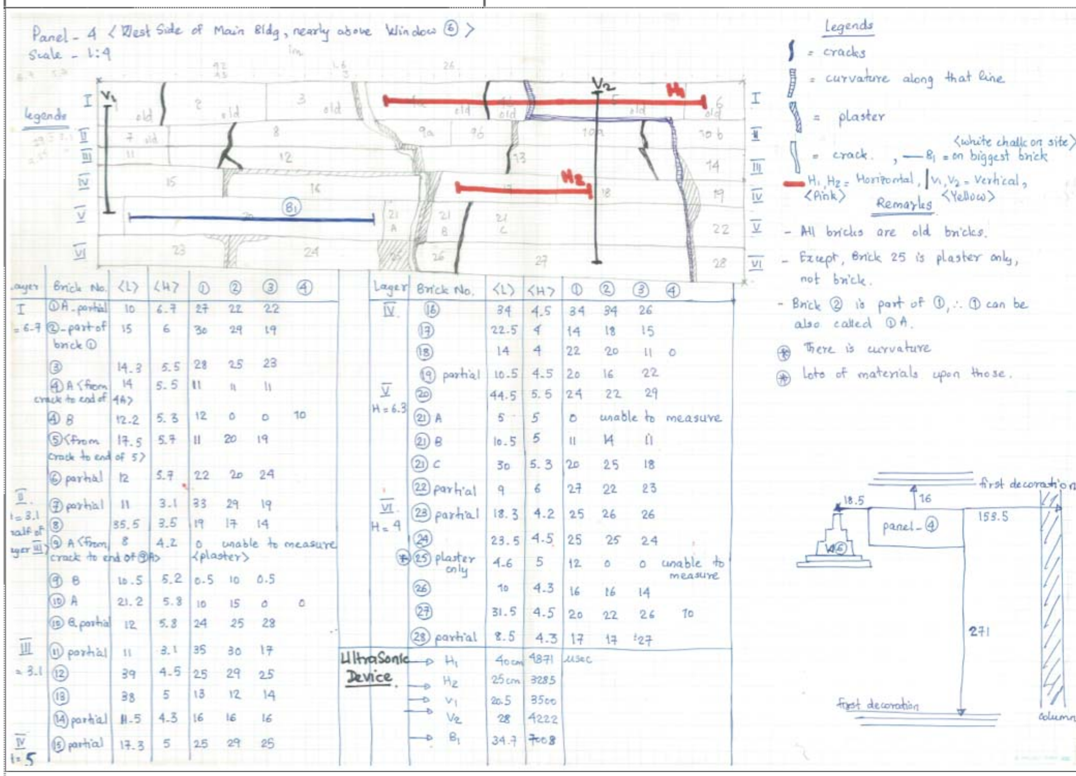


Fig. 21 The corresponding field notes and test results of rebound-hammer and ultrasonic test for the brick panel shown in **Fig. 20**. The colorful lines H1, H2, B1, V1 and V2 on the panel drawing indicate the measurement points where the ultra-sonic device was applied.

(*Source*: UNESCO, 2015)

5) Structural evaluation

This aspect of investigation concerns all the procedures performed to understand about composition of the structurally effective components, their hierarchy and relationship between different sub-components. The critical thing is to know the structural typology of the monument to be dealt with, and the correlation between primary and secondary element of structure in transferring the loads (permanent, dead and service, respectively) from the covering to the foundation. It is particularly significant also to obtain information about internal structure of the wall and the roof for the purpose of studying structural behavior as well as decomposition mechanism of a building. If there is any structural element which was added or modified by the past repair or reconstruction works, it must have considerable effect to the building and its behavior. It is therefore necessary to identify what element was added in what part of the building by using past records as referential sources. On the building which was already collapsed partly, direct observation of the internal structural composition is possible in such broken section at least. But, on the building that is still standing without a major collapse some kind of survey technology must be employed.

Endoscope

On the building without a broken section, the only way for visually inspecting directly inside of the structural body such as wall is the observation by inserting an endoscope through an open crack. The applied endoscopy is quite similar to the one used in the medical context, which can be inserted through a gap or a hole of about one centimeter in diameter. Still or motion pictures can be taken as well by high-end models. However, a built-in light on the head is usually not strong enough to observe overall image of the large internal void space, therefore, auxiliary lighting is recommended. Structural cracks rarely run linearly in a perpendicular direction to the wall surface, and making a hole by drilling is a more effective way to precisely understand the cross-sectional composition of the wall. In this case, destruction should be minimized by choosing an area with broken surface, for example, to avoid affecting to the heritage value. Bricks used in Bagan monuments are possible to be drilled with a hand drill. Drilled hole should be cleaned with a brush or blower before inserting an endoscopy to start observation. When any change of the internal composition is noticed, length from the wall surface to the changing point must be measured and recorded.

Fig. 22 A hand drill is used to make a whole into the wall of a monument through which the condition and composition of the wall can be investigated with an endoscope.

(*Source*: ©UNESCO/C.Rellensmann)

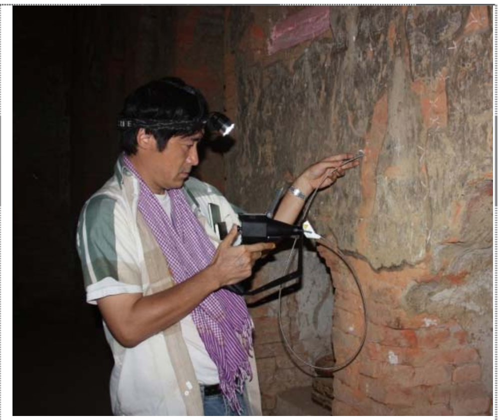


Fig. 23 The application of an endoscope through a drilled hole in order to investigate the composition of a wall.

(*Source*: ©UNESCO/C.Rellensmann)

Fig. 24 (left), **Fig. 25** (center), **Fig. 26** (right) Photos of the interior of a crack in a Bagan monument investigated through endoscopy.

(*Source:* Prof. Salvatore Russo, IUAV, 2015)

Infrared thermography

This technology is employed for the purpose of detecting any failure such as floating of the surface layer or existence of a void space behind the surface of a structure. The difference of the surface temperature can be observed as a visualized image by using an infrared camera. Traditional methods of visual observation as well as hammering test require a foothold to get access to the target area, but this technology enables observation from a distance. However, it is not applicable to the area where structural surface is covered with stucco and not exposed, of course. In such case, only information about floating of the finishing layer can be obtained.

Ground penetrating radar (GPR)

This device can be considered as an extension of the ultrasonic device described above and used when the investigated monument is large in scale and a high percentage of the structure consists of walls made with masonry or mortar. The equipment allows to judge the homogeneity and compactness of up to 50 cm deep very rapidly, which makes it possible to cover a wide surface in a short time.

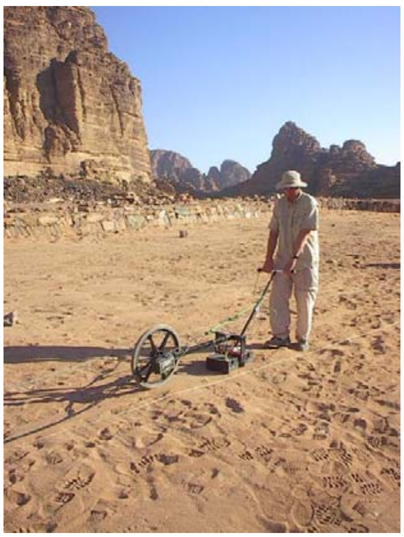


Fig. 27 Ground penetrating radar survey of an archaeological site.

(*Source*: https://en.wikipedia.org/wiki/Ground-penetrating_radar#/media/File:Radarsurvey.jpg)

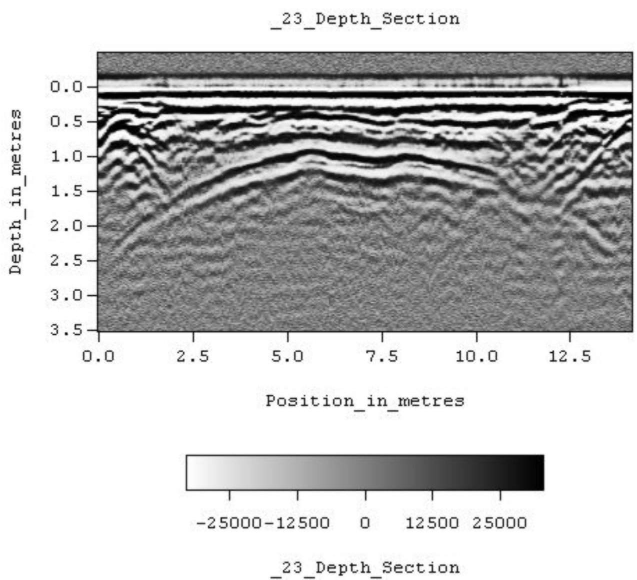


Fig. 28 GPR depth section (profile) showing a single line of data from the survey of the historic crypt. The domed roof of the crypt can be seen between 1 and 2.5 meters below surface.

(*Source*: https://en.wikipedia.org/wiki/Ground-penetrating_radar#/media/File:Radarsurvey.jpg)

Tomography

For detecting inside cavities of the thick wall of a structure, elastic wave tomography method is often used, in which velocity distribution section is obtained by receiving elastic waves propagating in the wall from a generating point on one face at multiple vibration reception points on another face. However, many of the monument structures in Bagan may originally have numerous cavities inside their walls, and thus effectiveness of this survey methodology here still needs to be verified. A variety of non-destructive survey methodologies by using X-rays or other technologies has been developed recently, whose application to the historic monuments is expected to advance rapidly.

Structural monitoring

For judging the degree of the risk to the structural stability caused by such degradation phenomena as displacement or cracking, it is important to know, together with the magnitude of the problems, if they are still continuing to progress. For the purpose of monitoring the structural displacements, high-precision measuring by using a 3D laser scanner, optical fiber distortion sensor and other systems have been developed and put in practical use in such field of the construction management of large-scale structures and maintenance of infrastructures.

At present, the most commonly spread methodology used for monument structures is the displacement monitoring applied for small gaps or cracks. The system most widely used consists of arch-shaped displacement transducers and a data logger. Since measuring at multiple points using this method creates problems because of the long cables and risk of a theft or damage, wireless data transmission systems with compatible transducers have been introduced in recent years.

Another more simple method for the crack monitoring is to attach across a crack a set of transparent gauges that consists of two overlapping plates with cross lines on their surface. Probably the cheapest as well as the simplest way - even if is a very approximate way to measure - is just to glue a thin piece of glass across a crack. Any movement of the crack will cause the glass to break, though degree and direction of the displacement cannot be observed accurately by this method.

Analysis of typical macro-structural element

As anticipated in the introduction of this sub-section 5) on structural evaluation, it is important to understand first the entire structural typology and the correlation between sub-structures which we can assume and consider as macro-elements. Generally, we can distinguish walls from roofs, and pillars or columns from other vertical members without any assigned bearing capacity. Towers have to be investigated to understand which parts of the structure have the task to transfer the upper load to the ground. Stairs can also be considered as a macro-element and, if incorporated into inside of a larger structure, understanding of their characteristics is vital.

Failure and collapse analysis

Failures and collapses observed and recorded in situ should be regarded always as symptoms of a previous, an existing or just occurred structural problem that have or are still affecting the investigated building. It may sound paradoxical, but these failures provide a good opportunity to learn what is happening, and why, with the structure. Such reading comprehension is not easy and needs to be done by an expert, but it always reveals precious information for the restoration of the building. Failure and collapse can be local, wide or global in terms of its extent. Failure and collapse could be only partial losses of materials or could be more. It is important first to understand precisely if they are concerned with primary structure, secondary structure or nonbearing parts. Because, this first diagnosis will influence strongly to the consequent decisions regarding further in situ investigation, interpretation or numerical calculation.

Affected element	*Characterization of crack*	*Potential causes*
Wall (without interventions)	Vertical	Vertical bending
	Horizontal	Horizontal bending
	Diagonal	Reached shear strength
		Differential vertical displacement of foundation
		Consequence of horizontal action
	Two diagonal around a corner (particularly near the windows)	Growing collapse mechanism of the corner and discontinuity of the covering; due to horizontal load and vertical depression
	"X" shape	Effect from earthquake, cyclic action
	Passes only through mortar	Lower level of stresses
	Passes also through bricks	Higher level of stresses
	Starts from holes/windows	Caused by lateral load and due to intrinsic vulnerability generated by windows/holes
	Extended and with crack width larger on the top than on the bottom	Out-of-plane rocking
	Extended but with similar width	In plane kinematism
Wall (with interventions)	Between new masonry and older masonry	Incorrect intervention; a different kind of intervention may be needed
	In the new masonry	Under-dimensioned and insufficient intervention
Column/pillar	Vertical	Reached bearing capacity
	Horizontal	Very rare, close to collapse
	Diagonal	Differential vertical displacement of foundations
		Consequence of horizontal action
		Effect of earthquake, cyclic action
	Vertical in the brick	Consequence of vertical load
	Vertical in the mortar with 'step' shape	Consequence of vertical load combined with lateral component of load

Table 3 Table for interpreting different kinds of cracks for failure-collapse analysis.

(*Source*: Prof. Salvatore Russo, IUAV, 2015)

6) Seismic evaluation

Bagan is located in a seismic area, and in fact many of the monument structures there suffered tremendous damage caused by the great earthquake in 1975. Evaluation of seismic performance of a structure requires professional knowledge of relatively high level, and currently the number of the capable experts is very limited. Nevertheless, since it is also true that this subject should not be excluded when discussing about structural stability of Bagan monuments, only brief outline of the basic seismic evaluation methodology is described below.

General concept and analytical approach

The latest seismic analysis concerning monumental structure or historical construction is done through a comparison between the expected demand and the effective capacity of the investigated construction to judge if the latter can satisfy the former. The first aspect - demand - is strictly related to the expected ground acceleration determined by the site characteristics as well as to the magnitude of the expected earthquakes based on the recent history. The demand depends also on the specific parameters which define the local soil. On the contrary, the capacity is influenced by the characteristics of the structure and its intrinsic potential dynamic performance, such as symmetry of the shape, regularity in distribution of the mass, degree of the structural conservation, quality of the connections between walls and roofs, as well as degree of degradation of the structural material which is dominant in the building.

Any rigorous seismic evaluation is then characterized by a proper numerical analysis through a Finite Element (FE) analysis, which is usually performed by using commonly available computer codes, and through the comparison of the obtained result with the experimental results. For the seismic analysis, two different types of numerical analysis are requested: the first one is related to a kind of serviceability limit state, the second one is to the ultimate limit state to avoid the total collapse. From the experimental side, it is particularly expected to know the mechanical properties of the target masonry and the experimental modal analysis is performed, in which the response of the structure is examined by using its overall mass and the stiffness value, to obtain the tendency of the structure's modal deformation. Finally, a comparison and a reciprocal calibration between FE analysis results and the experimental ones provide the result of the seismic analysis. From the seismic point of view, the structural restoration design, which reflects all the results derived from the General Methodology described in this document, is improved by this result.

The following values of peak ground acceleration in Bagan for different return periods were computed by the past study (Iziis 1983, vol. 3, p. 48):

return period :	50	100	500	1000 years
maximum ground acceleration :	240	300	460	530 cm/sec^2

Dynamic identification through ambient vibration

Experimental modal analysis is currently the only possible way to define the modal shape of a monument structure as a whole. This methodology is also useful to understand the tendency of displacements in case of a possible earthquake and to understand which sub-structural part is more vulnerable due to lower stiffness. Experimental modal analysis for the monument can be performed by installing local acceleration sensors at the significant locations of the structure. The ambient vibration such as pedestrian traffic, vehicular traffic, wind, noises, and rainfall is used as a natural input to activate the sensors. All sensors are usually connected by cables to a data acquisition system. A simple wireless system is nowadays becoming more popular. This investigation requires proper software and a data acquisition system.

Dynamic identification through local excitation

Another way to achieve the same result is through the use of a device (instrumented impact hammer) producing vibrations. In this case an adequate number of local excitation will be applied in all critical parts of the building to acquire the data. This investigation also requires proper software.

II-7 Laboratory testing

It is recommended to combine in situ investigation through non-destructive or micro-destructive diagnosis together with laboratory tests by means of destructive methods in order to obtain more comprehensive and reliable results. The results from laboratory tests can often confirm and validate the in situ structural investigation and also provide an opportunity to increase the number of tests thereby benefitting the statistical data and reliability of final results. Laboratory tests are usually performed to check the mechanical performance of bricks and mortar, as well as, to test the performance of brick-mortar masonry samples.

The sample dimensions are influenced by the condition of the masonry and should be limited in respect of heritage value of the monument. It is easy to collect brick or mortar samples from the building if they are already detached from the structure, but if the structure is still in a good condition the right place for extracting samples has to be carefully chosen.

We suggest following the international technical recommendations on tests and procedure of conservation of cultural heritage (respecting, if possible, the number of samples and their dimension).

To give an example, particularly standards for material testing in Japan are JIS R 1250 for brick material and JIS A 1108 for testing the strength of hardened concrete, which corresponds to ISO 1920-4:2005. British Standard uses BS EN 1052-4 methods of test for masonry.

High accuracy is necessary during the sampling to avoid any further damage to the historic construction, and mechanical disturbance on the sample. Then some rectification of the sample will be necessary before testing phase in the laboratory to avoid any irregularity which can influence in a negative way the results.

The tests have to be carried out in proper laboratories, and compression or universal machines have to be updated and calibrated before using. To get an acceptable result, the number of sample should be not less than three. For every sample, the identification number or code associated with the provenience and the characteristic must be marked directly on the surface, which is to be used in the all test records. For every test (evaluation of such mechanical parameters as strength, modulus of elasticity and amount of deformations against normal as well as tangential stresses), photographs before, during and after the test have to be taken.

Finally, the tests result in providing the automatically acquired data with the final load-displacement diagram.

Compression test on brick samples

(Objective)

- determination of the compression strength value by considering the mean value and the variability among the test results with the different tested samples
- determination of the experimental load-displacement diagram

(Procedure)

- extracting samples in cube shape (or in a regular shape) from the original brick
- measuring and rectifying dimensions of the sample to reach the tolerance of precision
- numbering each sample for identification
- execution of compression test
- recording of any visual or acoustic information during the test leading to the failure

(Analysis of results/implications for assessment)

- The tests procedure is recorded by the software of the machine. This produces two different sets of data: the first one about the displacements and the second one about the loads (both recorded during all the test process). These two different sets of data are used to generate the corresponding load-displacement diagrams through software already installed in every modern machine. The experimental diagram could be elaborated also through common graphic program.
- The so obtained result helps to define the structural conservation of the target monument in terms of approach, choice of technology and cost.

	
Fig. 29 Universal testing machine in the laboratory of the Myanmar Engineering Society (Hlaing Campus). (*Source*: Myanmar Engineering Society, Hlaing University, Yangon, Myanmar, 2015)	**Fig. 30** Measurements before cutting neat 4x4 cm test cubes. (*Source*: Myanmar Engineering Society, Hlaing University, Yangon, Myanmar, 2015)

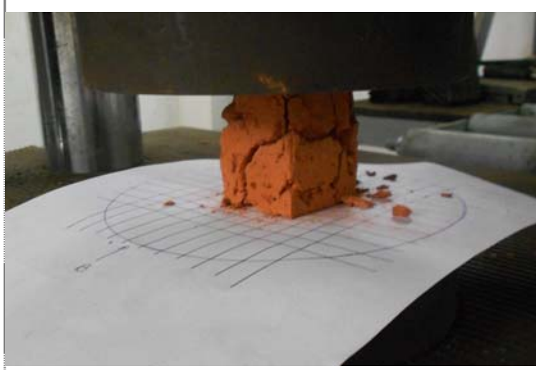



Fig. 31 The brick sample cube after testing. (*Source*: Myanmar Engineering Society, Hlaing University, Yangon, Myanmar, 2015)	**Fig. 32** Results from compressive strength test. (*Source*: Myanmar Engineering Society, Hlaing University, Yangon, Myanmar, 2015)

Compression test on bricks-mortar masonry

(Objective)

- determination of the compression strength value and its variability in different tested samples
- determination of the experimental load-displacement diagram

(Procedure)

- making in laboratory new mortar as much as similar to the original one present in the masonry (after previous analysis on original mortar)
- making in laboratory a masonry sample composed by at least three bricks bond by the new mortar
- measuring and rectifying dimensions of the masonry sample to reach the tolerance of precision
- execution of compression test (making sure that the top-surface of the masonry sample is perfectly adherent with the steel plate of the machine)
- recording of any visual or acoustic information during the test leading to the failure

(Analysis of results/implications for assessment)

- The tests procedure is recorded by the software of the machine. This produces two different sets of data: the first one about the displacements and the second one about the loads (both recorded during all the test process). These two different sets of data are used to generate the corresponding load-displacement diagrams through software already installed in every modern machine. The experimental diagram could be elaborated also through common graphic program.
- The so obtained result helps to define the structural conservation of the target monument in terms of approach, choice of technology and cost.

Four or three - point bending test (bricks)

(Objective)

- determination of the level of tensile strength in a brick under flexural action
- determination of the load-displacement diagram

(Procedure)

- preparation of sample with rectification of all faces respecting the original dimensions of the brick
- place the sample under machine with three or four bending point
- execution of flexural test
- recording of any visual or acoustic information during the test till the failure

(Analysis of results/implications for assessment)

- The tests procedure is recorded by the software of the machine. This produces two different sets of data: the first one about the displacements and the second one about the loads (both recorded during all the test process). These two different sets of data are used to generate the corresponding load-displacement diagrams through software already installed in every modern machine. The experimental diagram could be elaborated also through common graphic program.
- The so obtained result helps to define the structural conservation of the target monument in terms of approach, choice of technology and cost.

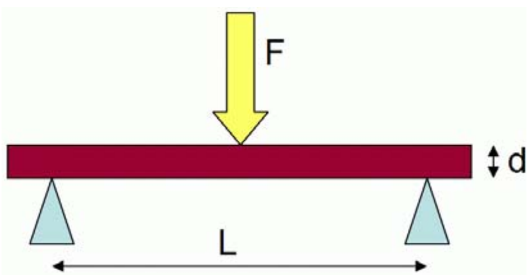


Fig. 33 The basic test setup for the three-point bending test. (*Source*: https://en.wikipedia.org/wiki/Flexural_strength)

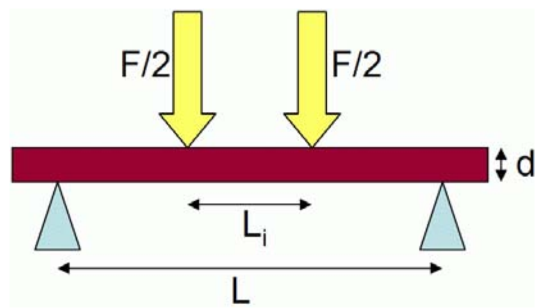


Fig. 34 The basic test setup for the four-point bending test. (*Source*: https://en.wikipedia.org/wiki/Flexural_strength)

Bond test

(Objective)

- determination of the values of tangential bond stresses and the corresponding slip
- determination of the experimental bond stress-slip diagram

(Procedure)

- creating a proper brick-mortar masonry sample by using three rectified bricks and new mortar in between them that is produced similar to the original one
- on top of the first brick the second brick is laid to overlap with half of the brick's length attached each other via mortar layer, then put the third brick in the same manner but in an opposite direction, which locates the third one right over the first one

- put up the sample on end in a direction making the first and the third bricks at lower side and the second brick at the higher side
- place it on the compression machine to conduct the test, so that the upper plate of machine is in contact only with the middle brick, while the lower plate is in contact with the two bricks at the outsides

(Analysis of results/implications for assessment)

- The tests procedure is recorded by the software of the machine. This produces two different sets of data: the first one about the displacements and the second one about the loads (both recorded during all the test process). These two different sets of data are used to generate the corresponding load-displacement diagrams through software already installed in every modern machine. The experimental diagram could be elaborated also through common graphic program.
- The so obtained result helps to define the structural conservation of the target monument in terms of approach, choice of technology and cost.

<u>Shear test</u>

(Objective)

- determination of shear strength of a brick-mortar masonry panel
- determination of the load which generates first shear crack
- determination of the shear experimental load-displacement diagram

(Procedure)

- creation of a square masonry panel having proper overall dimension for imitating the structural composition and the major dimension of the original masonry, at least its thickness
- place on the machine the masonry panel in a diagonal position (for any detail see the international technical procedures previously mentioned)
- execution of indirect shear test by applying only compression stress
- The machine used has to be appropriate in its capacity and dimensions as requested

(Analysis of results/implications for assessment)

- The tests procedure is recorded by the software of the machine. This produces two different sets of data: the first one about the displacements and the second one about the loads (both recorded during all the test process). These two different sets of data are used to generate the corresponding load-displacement diagrams through software already installed in every modern machine. The experimental diagram could be elaborated also through common graphic program.
- The so obtained result helps to define the structural conservation of the target monument in terms of approach, choice of technology and cost.

Chemical analysis

Although no detailed explanation on chemical analysis of the material is given in this document, it is necessary to evaluate the deterioration condition also from non-mechanical perspective, in order to precisely understand the correlation between the material deterioration and lowering of the strength. Examples are component analysis of the brick and measuring of porosity by means of water absorption test. Various kinds of chemical analysis are also conducted for producing a new material imitating the original one, not only in its composition but also in its density, specific gravity and other physical characters, such as the case of new mortar used for creating a brick-mortar masonry test piece.

II-8 Diagnosis of all collected information and final assessment

Putting together all the information obtained through the above-mentioned on-site investigation as well as laboratory testing and if possible the suggested numerical simulation, analysis of the degree and progress of the degradation of the target structure is performed to provide diagnosis for the condition assessment. At the same time, opinion about assumed main deterioration causes and mechanisms is compiled and stated.

In this process of condition assessment, it is usually not expected to carry out a full-scale structural analysis by using the collected mechanical properties. It is also particularly difficult to perform a seismic evaluation with precision from the limited amount of information about the internal structural composition. Instead, a report about identification of the extent of degradation and analysis of its multiple causes is produced, which should be saved together with all the collected data in both hard copy and soft copy version for future utilization in the preservation and management of the target monument. Such reports will also be useful as reference material to choose the appropriate approaches for any follow-up structural investigations or assessments.

II-9 Recommendations for intervention

Based on the results of the detailed condition assessment, recommendations on desirable actions that should be performed immediately or are proposed in the short-term. The main options of such action are assumed as described in a sequential manner below.

Emergency measures

In case degradation is already in advanced stage and the structure is decided to be in dangerous condition in view of stability, urgent measures for its temporary stabilization should be recommended. Installation of timbering supports to the unstable portions, provision or renewing of covering or proofing layer from water leakage, establishment of the off-limit area, cutting trees and other actions would be anticipated.

Supplementary investigation

With regard to problems affecting structural stability which were identified by the detailed condition assessment, further specialized investigation should be implemented, in order to make it clear the cause and mechanism of the problem in even more detail.

Monitoring

In case it is uncertain if an identified degradation phenomenon is still in progress or already settled, continuous monitoring should be started to observe increase of displacement or progress of degradation. Also, contributing information to clarify the degradation causes will be obtained by researching effects of seasonal change and other factors. For analyzing the degradation mechanism, it is effective to conduct structural monitoring in combination with environmental monitoring.

Conservation and restoration intervention

Basic outline of the expected area and manner of the intervention should be suggested when it is decided that the structure is in such condition of requiring partial or total conservation or restoration. Design for the actual intervention must be made separately as a part of the conservation project after referring results of supplementary investigations and /or monitoring.

III PILOT CASE STUDY REPORT

III-1 Outline of the target monument (No. 1249 Phya-sa-shwe-gu)

1) Selection of the target

For this pilot case study of the in-depth condition assessment, the optimal conditions to be the target building are summarized below.

・Its dimensions should be moderate, not too large nor too small.

・The material and structural style applied should have no special characteristics, but standard configurations.

・ It should not be under a specific condition that can be rarely seen, but shows a common deterioration status.

・Its deterioration and damage should be still on the way, not be completely done yet.

・ It should not experience yet a full-scale conservation measures nor renovation, so that the deterioration states can continuously be observed.

・There are few tourists and visitors to the building and also its location is easy to be accessed and to work at.

・Its upper structure shall be safely accessible and its entrance should be able to be locked.

We were searching for the building that possessed all these characteristics when we conducted a survey in January 2015 and selected Phya-sa-shwe-gu temple (No.1249) as an appropriate target building for this project.

2) Outline of the monument

This temple is located in Myinkabar village, where is approximately 1.5 km to the south from the southern edge of the Old Bagan city wall. Behind a village which has a large number of lacquer work ateliers, there are roughly ten sets of the monuments that are vary in size from small to large as a group on the upper part of the river terrace on the left side of Ayeyarwady River. On the north there is a pagoda No.1250 and on the south there is a temple No.1242 next to each other in a row in the north and south direction. No. 1242 was recently rebuilt on structural remnants that had only a foundation and the style of its upper structure is in a pseudo old style having no historical evidence. On the other hand, Buildings No. 1249 and No. 1250 relatively remain their original forms, apart from the recently restored top parts. Judging from their dimensions, No. 1249 seems to be a central shrine among this group of buildings.

No.1249 is assumed to have been built in around the 12th century, which is a brick-made temple, facing the east and has a single story structure. It consists of the main part with a corridor that has vaults surrounding a central pillar and an entrance hall with a square plan being adjoined to the eastern front of the main part. There are a square tower right above the central pillar and also corner towers on the all four corners. There is only one entrance at the front porch of the entrance hall and there are three windows on each of the north, west and south sides of the corridor and one window each on north and south faces of the entrance hall. The stairs installed inside the south wall of the entrance hall lead to the roof level, on which the top of the entrance hall forms a terrace. The dimension of the entire plan is approximately 23 m in the east-west and 14 m in the north-south.

Both the exterior and interior were originally finished with stucco and walls and ceilings in a hall are decorated with mural paintings of Buddhist narratives and floral patterns. On four faces of the central pillar Buddha statues in seated posture are placed and also other seated Buddha statues are enshrined in a large number of niches on the interior walls of the corridor for each. All those statues were remodeled at the time of recent renovation or newly enshrined. The central tower, corner towers, parapets arranged in the peripheral part of the roof, the east face of the entrance hall and the pediment area of the porch were all recently reconstructed. In various parts of both the interior and exterior of the building there are traces of repair with cement mortar. However, no reinforcing measure that can affect structural behavior of the building was taken until today.

3) General condition of the monument

The current state of preservation of the building is that relatively large deformation and cracks are found mainly around the outer walls of the corridor, although there is no collapsed roof. It also seems to have multiple degradation features, such as uneven settlement of the outer wall foundation, outward leaning of the middle part of walls and deformation of the upper vaults. Besides that, its degradation includes poor drainage at the foot, luxuriance of plants on the roof and intrusion of the rain water. From above noted conditions, we judged that this structure shall be suitable as the target building for a comprehensive study of the degradation mechanisms exist.

III-2 Site preparation and basic documentation

1) Clearance of vegetation

When we selected the building as the target, weeds and shrubs were growing everywhere in the surroundings as well as on top of the building. In preparation to start documentation works in April 2015, DOA workers cut and removed all vegetation from the roof and direct vicinity of the building.

2) Documentation of the monument

Detailed documentation of the target monument was made as “Photogrammetry workshop” in April to May 2015, in collaboration with Carleton University team lead by Prof. Mario Santana Quintero and DOA. This workshop was designed as an opportunity of capacity building training for the DOA technical staff to document Bagan’s built heritage. The workshop introduced and demonstrated basic hand surveying and drawing techniques as well as IT-supported techniques such as photogrammetry and 3D laser scanning in order to produce 2D drawings such as elevations, cross-sections, ceiling plans and floor plans of Phya-sa-shwe-gu temple. The actual field work took place for 10 days from April to May 2015 including implementation of a comprehensive training program. The collected data was processed and measured drawings were produced together with other detailed documents by spending a month in Canada. In the field work, starting from setting up of the surveying network by using Total Stations, the objective building was measured both by hands and with TSs. Photogrammetry technique using “structure from motion” or SfM was applied to obtain scaled 3D images where a UAV drone device was also employed to capture upper sections of the building.

For more details of this work, refer to “Report on Documenting Bagan’s Built Heritage” prepared by the Carleton Immersive Media Studio (CIMS).

3) Installation of scaffolding

In order to secure safe and easy access to the area to be investigated, it was decided to set up temporary scaffolding along three faces in the north, west and south of the exterior walls of the building's main body. Height of the scaffolding was up to the level over cornice of the exterior walls. Bamboo pole was used as the material that was tied with hemp ropes to build double row scaffolding. A row of several bamboo pipes tied each other with ropes was used as a movable floor board. For inside of the building, a set of steel-made rolling tower and aluminum ladders were used as necessary.

Fig. 35 Phaya-shwe-gu Temple with scaffolding installed for the areas that needed to be inspected, plus a moveable scaffold that can be used for accessing different parts of the exterior building.

(*Source*: ©UNESCO/M.Tomoda)

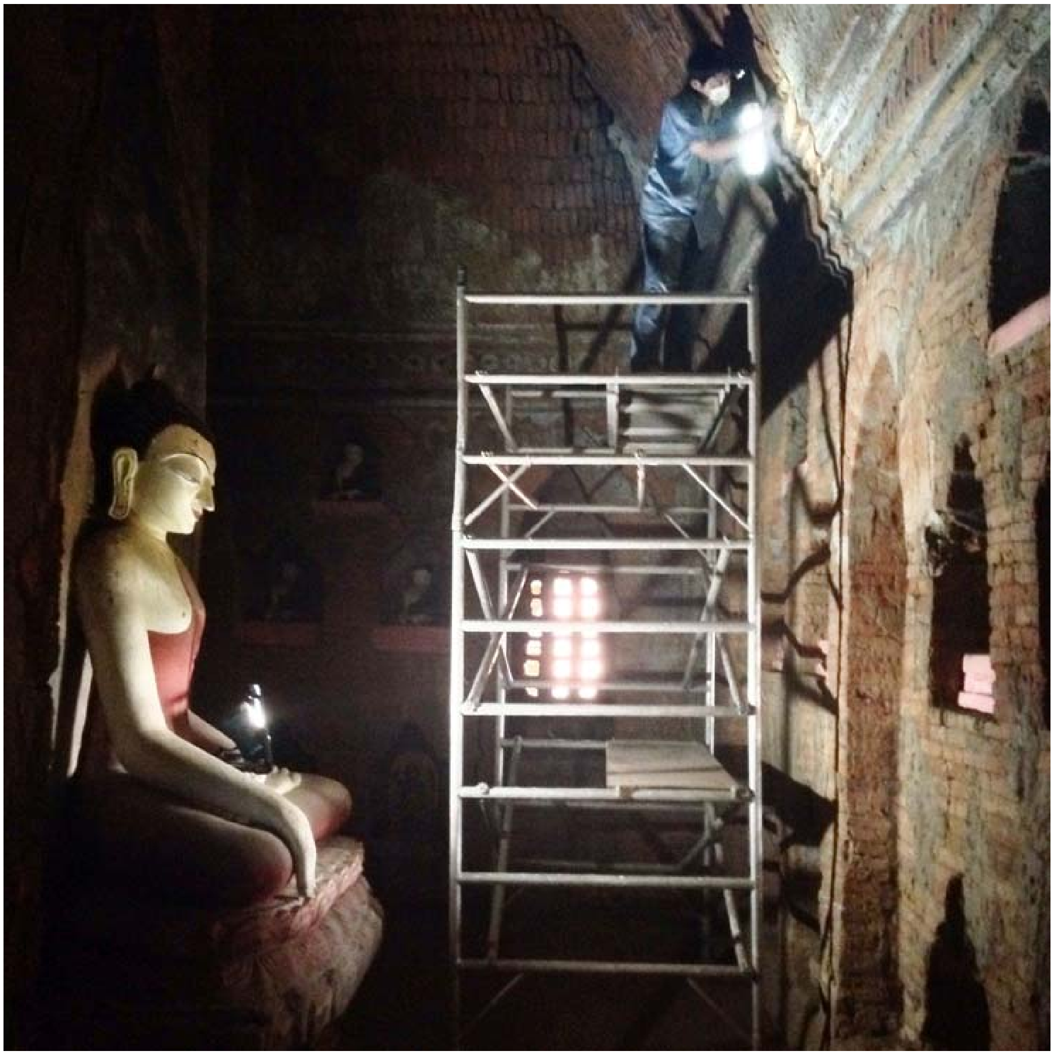


Fig. 36 The moveable rolling tower that was used inside of the building together with aluminum scaffolding.

(*Source*: ©UNESCO/C.Rellensmann)

III-3 On-site investigation

On-site investigation was conducted in the following three periods.

i) 28 to 30 April 2015 (preparatory inspection for developing a methodology)

ii) 11 to 18 June 2015 (main investigation + training for DOA staff)

iii) 27 to 30 September (supplementary investigation + training for DOA staff)

The members to participate in the works are as follows.

Masahiko Tomoda	(NRICPT)
Salvatore Russo	(IUAV University of Venice)
Mara Landoni	(Scientific University “Politecnico di Milano”)
Clara Rellensmann	(UNESCO Myanmar)
Saw Htwe Zaw	(Myanmar Engineering Society)
Pwint	(Association of Myanmar Architects)
Wint Tin Htut Latt	(Association of Myanmar Architects)
Saw Htwe Zaw	(Myanmar Engineering Society)
Soe Soe Lin	(Deputy Director, DoA Bagan)
Staff members of DoA	

1) Visual observation

The west wall is characterized by the presence of three major cracks located in substantial correspondence to the three windows. These cracks/discontinuities are extensive, deep and wide. The same wall also has two kinds of out-of-plane bending behavior in vertical and longitudinal. The mentioned cracks are also present inside the temple in the same position.

The wall-corner area between the north and west walls is affected by two major cracks that are symmetric and represent the confirmation of a progressive and dangerous out-of-plane behavior, again; the concomitant presence of the corner tower enhances the complex displacement. This complex damage is also partially consequence of the incapability of the walls to support the horizontal load transferred by the very heavy covering and the main tower. Another phenomenon of out-of-plane displacement is seen with the entire north wall, though it is less significant than that with the west wall.

Five major clacks are observed on the external walls of the main body, which develop from the beginning of the cover to the base of the building. The specific nature of the cracks more important is the fact that they affect the entire walls in all their height, confirming the serious situation of structural degradation in which the temple is located.

A large and important vertical crack/discontinuity causes the separation between the main body and the entrance hall. The corner tower located on top of the corner between the north and east wall of the main body is particularly damaged and at risk of collapse partly because of the local damage of bricks, as well as of the growth of vegetation on it.

More generally, all the windows are showing advanced structural decay. They are critical elements of structural weakness and vulnerability, together with the niches on the interior face of the walls, contributing in fact to the reduction of available sections to withstand compression stresses. In other words, the sections entirely resistant are in fact only the angular portions, where it concentrates the highest stress level in the masonry. To confirm this, most of the short pillars which separate the niches appear dangerously degraded from the viewpoint of reduction of the original sections.

Nevertheless the central pillar is at the moment in a good condition of conservation.

The presence of a soft or at least not rigid ground that is typical in the area induced permanent deformation and displacement that affect the monument independently by external events, such as an earthquake, or as a result of the structural decay of the temple and the dead load. The excessive apical load which is common with such type of temples, together with the asymmetrical structural configuration in this case, makes weaker the wall opposite to the entrance hall producing a dangerous tendency to the out-of-plane displacement or the expulsion of important portions of the masonry. The phenomenon as a whole could also be favored by a shallow foundation and a little cohesive soil.

Selection of appropriate methodologies or devices for on-site structural investigation of architectural heritage can be influenced by many different factors as well as specific given constraints such as time and budget restrictions. It is also strongly depending on the specific characteristics of the target construction, including its overall dimension and type of the dominant structural material (i.e. masonry, stone or wood). The combined use of rebound hammer, ultrasonic test and endoscopy should be the first choice for quick and easy structural assessment. Nevertheless, the visual observation remains the first common and reliable way for properly choosing the equipment for on-site structural diagnosis. For example, the presence of evident cracks always requests the use of endoscopy to measure the depth and type of fracture inside each discontinuity. Also, presence of a very old brick-mortar masonry suggests the necessity to evaluate its residual compactness by using rebound hammer and the efficiency of brick-mortar joints through ultrasonic test.

2) Excavation survey

At present, the foot of this building is paved with bricks, which was done by DOA in several years ago. We conducted surveys at the site aiming at these three points stated below.

① To know the original shape of the area where has been paved recently.

② To acquire information on the foundation of the building

③ To examine the possibility that the distortion of an upper portion of the structure might result from subsidence of the foundation.

To prevent excavation from making the upper section of the structure further unstable, we dug a L-shaped trench, whose dimensions are in the east-west direction 3.5m and in the north-south direction 2.2m, from the southeast corner of the main body to the connection part attaching to the south wall of the entrance hall, avoiding the part where deformation was obviously found. The survey period was from the 15th June to the 18th of June 2015 and the surveyed area was approximately 4.4m2.

Fig. 37 (left), **Fig. 38** (right) The surface excavation of the foundation at temple 1249.

(*Source*: ©UNESCO/C.Rellensmann)

After removing a brick pavement on the top surface and then a sand layer underneath, a brick-paved surface, which is about 25cm width, was discovered along the southern edge of the trench. These bricks seem to be rather recent ones and are standardized products with a smaller size than the ones on top surface. They can be considered to form a berm attached to the side wall of a terrace along the outer periphery of a reconstructed building No.1242. We decided to maintain this floor surface and dig down the remaining area. After digging down a silt layer containing brick fragments, river stones and pottery pieces up to 230 mm under the present floor surface, change in soil quality was recognized. In that layer, pieces of stucco relief were discovered at the north end of this section and these pieces can be thought to have peeled off from the upper part of a wall. Therefore, we concluded that this layer shall be the ground surface of the medieval times. Then, by digging down within a disturbed layer containing a great number of large-sized brick, pottery and stucco fragments, a floor surface paved with large bricks were found at the east section of the trench. In terms of the levels on this floor, it is highest at the north end and becomes lower toward south. Judging from the remaining condition of mortar on joints, it can be thought that the top surface of bricks in the middle that almost preserves its original shape (on the level of an underground depth of 280mm) was the original floor surface and the irregularly configured brick surface was the base stratum under the top brick layer that has already been lost. In contrast, the floor surface found at the south side of the trench (on the level of an underground depth of approximately 450mm) was quite orderly formed and some mortar filled in the joints between bricks remained. It is therefore highly probable that it used to be a finishing surface. If it was the case, the floor surfaces shall have the difference in level. However, it is impossible to draw a conclusion at this moment from only the state of the limited area where has already been excavated. The dimensions of bricks used on both higher and lower levels of floors are approximately 420×200×55 mm and in both cases they seem to be of the same kind. Therefore, it can be presumed that the floor should be original. Although this type of floor face was not found in the western half of the trench, judging from the remaining condition of mortar filled in the joints and the quality of earth containing fragments of brick, we can infer that the brick paving in that area had been removed for some reason. The height of an indoor floor currently covered with mortal seems to be equal to the higher one among these two different original floor levels in exterior, though still the original height of the indoor floor is unknown.

At the west end of the trench, a sub-trench that measures 1.0 m from east to west was set and we further dug down the earth. We saw the change in the quality of soil at the underground level of about 580 mm below the current floor surface. Under that level, the soil is well compacted and even in the quality, having very few brick and ceramic pieces. At the underground level approximately 620 mm, the bottom edge of the building foundation was found and therefore we decided to finish up the excavation at the level of 800 mm deep from the present pavement level. The final layer we excavated seemed to be the one for leveling ground, which continues to a further lower level. We however could not conduct survey with equipment such as an auger and therefore the level of the natural ground surface is still unidentified. From what we observed in sections of the excavated area, there was no trace of any tamped layer.

At least in a peripheral part, from the undermost layer of brick was directly installed on the leveled ground and from that layer up to the third layer brick was vertically laid, after which, in a setback state of about 70mm, from the fourth to the ninth layers brick was uprightly laid. The tenth is also arranged in a setback state of roughly 70mm, whose top face is almost equivalent to the present pavement surface. The upper surface of the third layer of brick corresponds to the lower floor level above noted and the top face of the sixth floor is equivalent to the higher floor level described above. At the entrance hall part of the structure, over the seventh layer molding was formed. The outside surface of the sixth layer is evenly arranged to the one of the seventh layer. Since under these levels it has not been excavated yet, the shape and the depth of the foundation of this part are still unknown.

Looking at the excavated brick walls, the weathering near the eighth layer and above seems to be severe. This level is almost the same as the one we concluded to be the ground surface of medieval times. The remaining part might have been buried from a relatively early stage.

Meanwhile, there is a gap on the brick wall above the top face of the fifth layer at around the southeast corner of the main body. From the observation, it can be noticed that the gap stretches in a stepped pattern into an internal corner where the entrance hall is attached to. From the measurement results of the ninth layer shows that there is approximately 15 mm difference in level between two points separated from each other by 60 cm, which is possibly caused by an uneven settlement of the ground.

The points that have been revealed through this excavation and observation can be summarized as follows.

1) The shapes of the foundation parts of the main body structure and an outer wall of the entrance hall.

2) The shape and depth of the foundation of an outer wall belongs to the main body.

3) At least in the area we investigated, no foundation work was found at the bottom. A building structure was directly constructed on the leveled ground layer.

4) The outer peripheral part of the building has had a brick paved surface since it was originally constructed.

5) Uneven settlement occurred at the foundation, which possibly relates to the deformation of its upper structure.

After the excavation, the trench was refilled with sandbags in preparation for a possible additional survey to be conducted in the future. All excavated pieces of earthenware and stucco among other articles are kept at the DOA Bagan branch office.

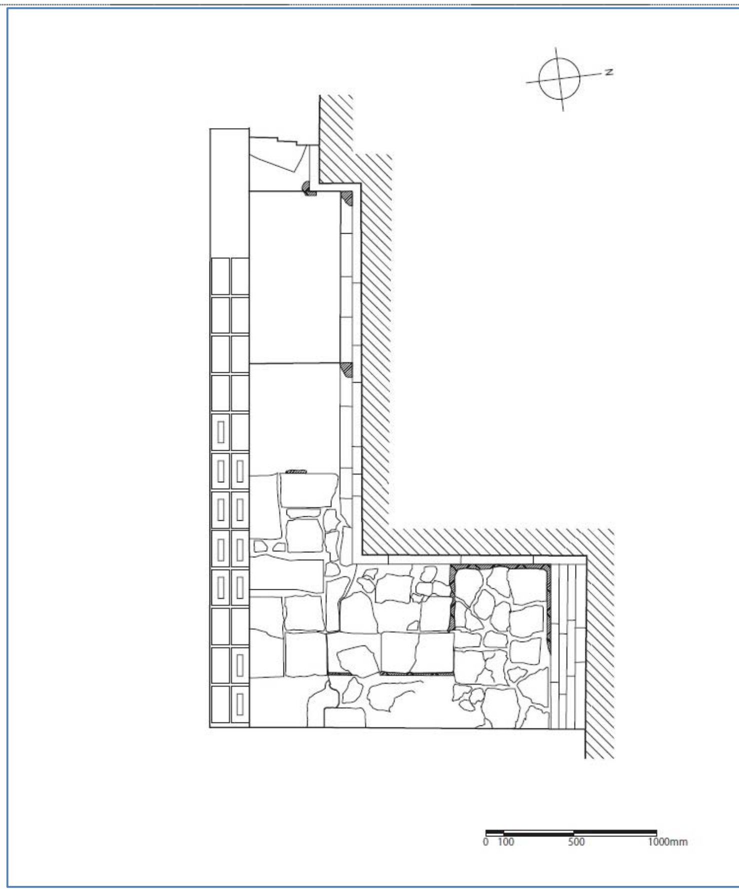


Fig. 39 Plan of the excavation trench.

(*Source*: Prof. Masahiko Tomoda, National Research Institute of Cultural Properties Japan (NRICPT), 2015)

3) Measurement of crack and displacement

Crack pattern recording

In order to analyze the magnitude of degradation and its effect to the overall structural stability, major cracks observed on the exterior as well as interior surfaces of the structure were inspected and recorded.

Most of the cracks occurred on the entrance hall were filled in and consolidated by the past repair works, and it might be also the case with upper portion of the main tower. On the other hand, no obvious crack was seen on the central pillar inside the temple. Therefore, cracks on external walls of the main body and those on the west interior wall of the entrance hall were mainly recorded and measured this time.

First, we marked with yellow colored chalks directly on the brick surface all along the crack line from its start point to the end including its major branches. Then, the crack lines were recorded by drawing on the elevation drawings. Total length of the crack and width at some intermediate positions including that of the widest gap were measured by using a tape measure. Photographic recording was also made both globally and locally for each crack line.

In total 10 crack lines on the exterior of the main body were recorded with measurement, while 20 on the interior walls as well as the ceiling and 4 on the interior west wall of the entrance hall, some of which seemed to be corresponding each other. The largest gap (60mm) was recorded with crack N3 on the north exterior face of the main body. Some of large cracks such as W3 on the west exterior face of the main body show displacements not only in-plane direction but also out-of-plane direction.

Phya-Sa-Shwe-Gu Temple									
Condition Assessment (July 2015)									
June 2015 Working Section									
North (Exterior) Crack Pattern									
No.	Location	Starting Point	Ending Point	Type	Wide	Length	Direction	Speculatry	Short Remar
N1	Left window of the main building	from the first pediment	to the base of the platform of the temple	Crack	N1C1: 0.4 cm N1C2: 0.9 cm N1C3: 0.5 cm	975 cm	Slightly Diagonal	_	Brick Decay side of wall
N2	Middle window of the main building	from the first pediment	to the base	Crack	N2C1: 0.5 cm N2C2: 2.3 cm N2C3: 1.3 cm	1127 cm	Vertical	_	Continuous through to t window
N3	Right window of the main building	from the first pediment	to the base	Discontinue	N3C1: 0.5 cm N3C2: 6.0 cm N3C3: 2.5cm N3C4: 5.0 cm	988 cm	Slightly Diagonal	_	Very Big Cra is moving ou
N4	Lower Right, upper left form window	from pediment	to upper base	Crack	N4C1: 0.5 cm N4C2: 1.8 cm	520 cm	Vertical	_	_
West (Exterior) Crack Pattern									
W1	Left Side	from the first pediment	to the base	Discontinue	W1C1: 1.0 cm W1C2: 1.8 cm W1C3: 2.2 cm	940 cm	Slightly Diagonal	_	with 3 crack crushing wir (moving out
W2	Middle	from the first pediment	to the base	Discontinue	W2C1: 1.5 cm W2C2: 2.5 cm W2C3: 3.5 cm	880 cm	Vertical	_	1 Big Crack v minor cracks diagonal mo cushing win
W3	Right side	from the first pediment	to near base of window	Discontinue	W3C1: 1.3 cm W3C2: 2.0 cm W3C3: 3.0 cm	650 cm	Vertical	_	Not only hor carcking but moving outv
South (Exterior) Crack Pattern									
S1	Left Side	from pediment	to the side of the window	Crack	S1C1: 1.0 cm S1C2: 0.8 cm S1C3: 1.3 cm	240 cm	Vertical	_	with 3 crack crushing wir (moving out
S2	Middle	from pediment	to the base	Crack	S2C1: 0.2 cm S2C2: 0.3 cm S2C3: 1.0 cm	380 cm + 350 cm	Vertical	_	2 main Crack
S3	Right side	from pediment	to the side of the window	Crack	S3C1: 1.0 cm S3C2: 1.5 cm S3C3: 0.7 cm	340 cm	Slightly Diagonal	_	_

Table 4 Sample of a table to record key information about individual cracks.

(*Source*: UNESCO/DoA/AMA, 2015)

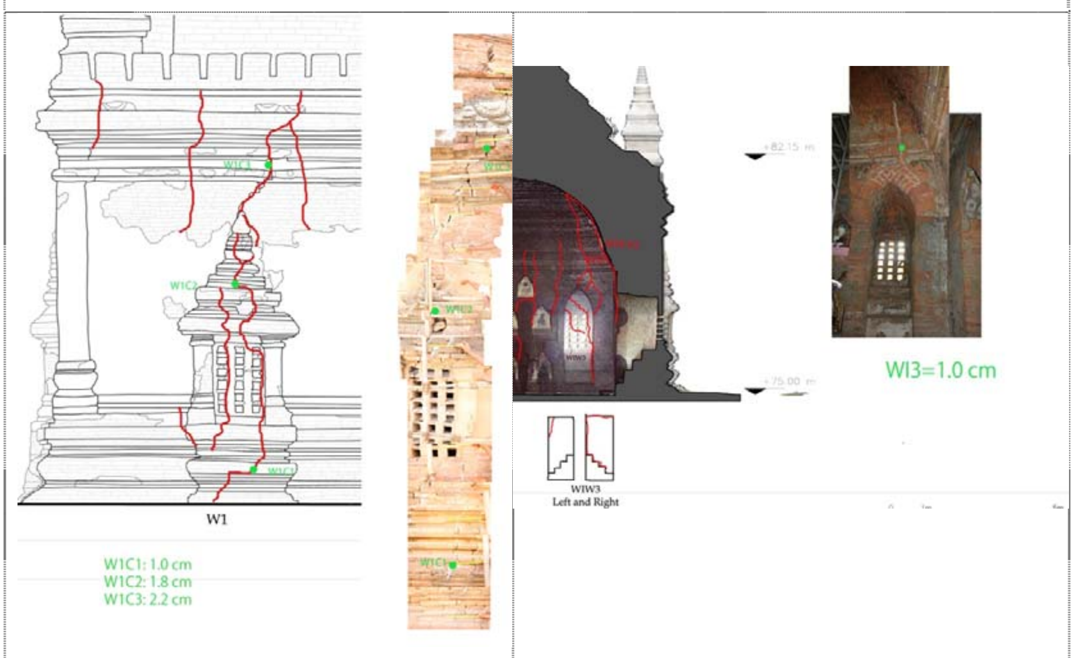
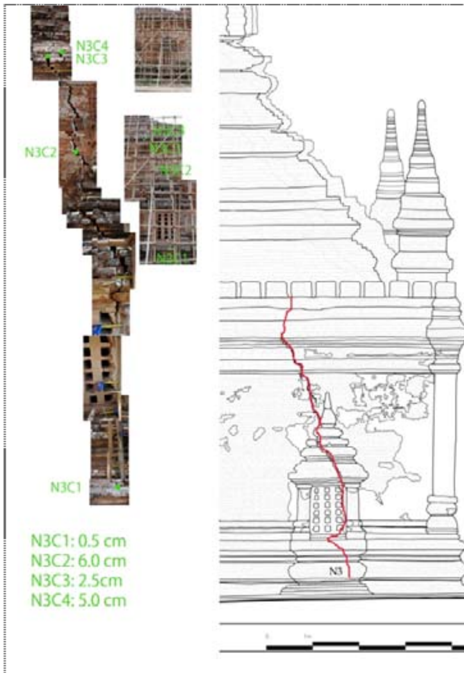


Fig. 40 (left), **Fig. 41** (right) The digital documentation of two corresponding cracks on the exterior and interior wall of a monument.

(*Source*: UNESCO/AMA/DOA, 2015)

Fig. 42 The cracks were marked with chalk and then documented in detail with a scale bar in the photo to provide information about the width of the crack.

(*Source*: ©UNESCO/C.Rellensmann)



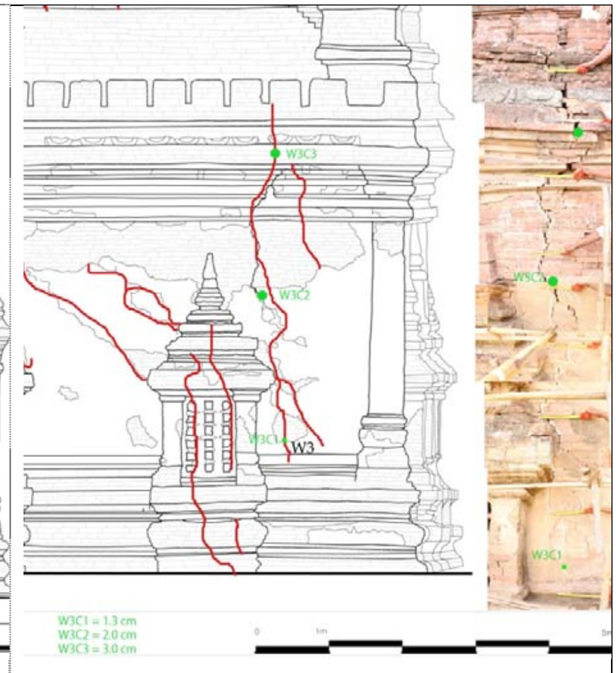


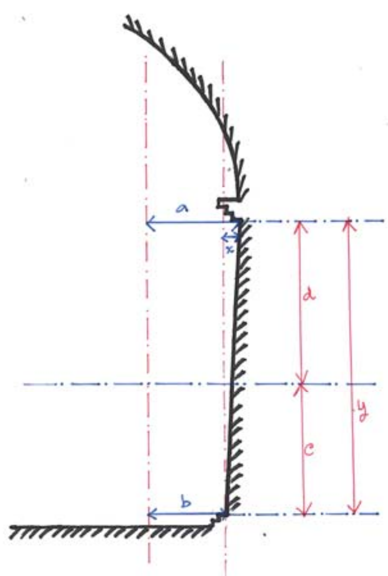
Fig. 43 (left), **Fig. 44** (right) The result of the detailed crack pattern documentation of two of the major cracks of PSSG temple on the north and west façades.

(*Source*: UNESCO/AMA/DOA, 2015)

Measurement of displacement

Even simply with visual observation, it is obvious that external walls of the main body occurs out-of-plane displacement particularly in the middle section of west face. This time, 3D laser scanning technology was applied for basic documentation of the structure, which made it possible to obtain horizontal section measuring data at any height. Horizontal section drawing at two different heights, one at the top level of exterior cornice and another at that of interior cornice, show outward displacement of the middle section of the walls on the north and the west.

We manually measured the degree of the displacement. We first established on the floor inside the building four base lines crossing at right angles by using a total station, and then measure horizontal distance from the line to the interior wall surface at its bottom and top (directly below the cornice) at approximately equal intervals of one meter. The result was as we expected showing that the west and north walls lean outward in their middle sections significantly, though south wall as a whole lean in an opposite way. The largest amount of displacement was measured at point W6 in the middle of west wall where difference or displacement value was 154mm between the bottom and top of the wall with height of 3700mm.



x = a – b = outward displacement

y = c + d = wall height

x/y = leaning angle

Fig. 45 Sketch indicating the type of measurements as undertaken at temple no.1249 for measuring displacements.

(*Source*: Prof. Masahiko Tomoda, National Research Institute of Cultural Properties Japan (NRICPT), 2016)

We also tried to evaluate the degree of displacement by measuring height at the top of cornice on the same interior walls by establishing horizontal base lines on their surfaces. However, we could not see any clear tendency from the obtained data.

Fig. 46 (left), **Fig. 47** (right) DoA team and international experts are measuring the displacement of walls at the target monument.

(*Source*: ©UNESO/C.Rellensmann)

4) Structural material analysis

Collection of samples for laboratory testing

Brick samples were collected from the monument to be served for a laboratory testing to obtain information about the material strength. In total 23 pieces of brick were collected, 16 from inside the main body, two from the entrance hall, one from the stairway and four from the roof top terrace at the bottom of the main tower. Among these three pieces (S-1, W-1, TN-4) were obviously new ones which might be brought in from outside possibly for the use of some recent intervention. The rest 20 pieces seemed to be ancient ones judging from the shape and dimension, though only one (EN-1) of them still kept its complete shape. We decided not to take any brick still in its original position or with any trace of carving or finishing on its surface. Thus, all the collected samples were found on the floor or on the windowsill, and it is in fact impossible to assert that these pieces originally belonged to this structure. However, we could estimate provenance of W-2 and ES-2 as the corresponding absence of brick was found at the position directly above the location of each piece, which enabled us to judge them as original structural materials of this building. For details of the laboratory testing, refer to the section III-4.

Brick samples for testing from Phya-sa-shwe-gu, temple no.1249

#	No.	location	Dimension (LxWxD in mm)	Origin	Remarks	Suitabililty for testing (sclerometre)
1	S-1	1st window	220x105x45	unknown	hole in the middle	11-17-19-22-24
2	S-2		285x190x50	unknown	new brick	22-22-21
3	S-3	2nd window	180x160x50	unknown	old brick	12-12-11
4	S-4	2nd window	180x160x50	unknown	old brick	20-20-[12-16-18]
5	S-5	2nd window	350x210x65	unknown	old brick	26-28-24
6	S-6	2nd window	160x160x45	unknown	old brick	12-15-13-13
7	S-7	3rd window	160x110x55	unknown	old brick	unable to conclude th because brick broke d test
8	W-1	4th window	200x100x55	unknown	new brick [hole in the middle]	21-23-14-18
9	W-2	4th window	155x120x55	from vault above window	old brick	16-15-16
10	W-3	4th window	210x165x60	from vault above window	old brick [broken, W3a and W3b]	18-12-20
11	W-4	5th window	220x180x60	unknown	old brick	19-19-21
12	N-1	7th window	220x175x60	unknown	old brick	20-16-14-18
13	N-2	9th window	180x135x55	unknown	old brick	22-30-28
14	N-3	9th window	300x195x70	unknown	old brick	18-[23-28-24-22-23]
15	N-4	9th window	210x165x70	unknown	old brick [original edging?; cut inside]	24-25-20-21
16	N-5	9th window	490x330x200	unknown	sculpture piece	(X)
17	eN-1	entrance hall north window	325x200x60	unknown	full brick [old brick]	24-28-28
18	eS-1	entrance hall south window	250x200x60	unknown	old brick	24-28-28
19	eS-2	southern stair way	200x250x55	from upper part of ceiling		unable to test
20	TN-1	terrace	430x225x65	unknown	old brick	21-18-28-23
21	TN-2	terrace	180x225x65	unknown	old brick	12-12-12
22	TN-3	terrace	230x200x60	unknown	old brick	from 45 [22-20-18]
23	TN-4	terrace	220x100x70	unknown	new brick [hole in the middle]	16-16-22

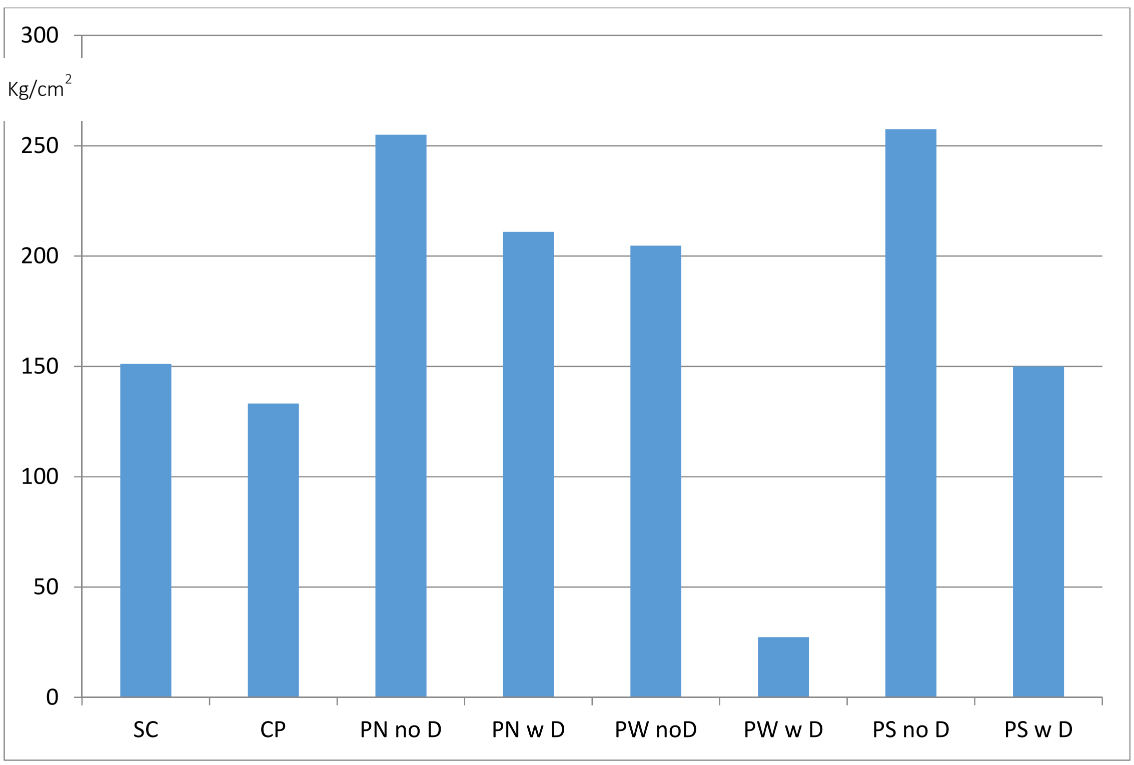
Table 5 A table for recording key information about the collected brick samples such as number, location, origin, and suitability for testing.

(*Source*: UNESCO/AMA/DOA, 2015)

Rebound hammer test

Rebound hammer test was conducted to estimate compression strength of the bricks in different areas of the structure. We selected two areas, one without damage and another with obvious damage, for each of north, west and south exterior facades on the main body of the building. Also, two areas on south and west faces of the central pillar, as well as one area for each of four sides of the interior wall at the decayed lower column between niches were selected to be the target areas of this test. The rebound hammer was applied to every brick in the rectangular area three times at least in order to obtain reliable results.

After deduction by using a conversion table, the obtained mean value of the compression strength of the bricks in each testing area is shown on the bar graph below.



<Tendency of compression strength value of the bricks>

Legend: SC=short columns, CP=central pillar, PN =north façade, PW=west façade, PS=south façade, no D=without damage, w D=with damage

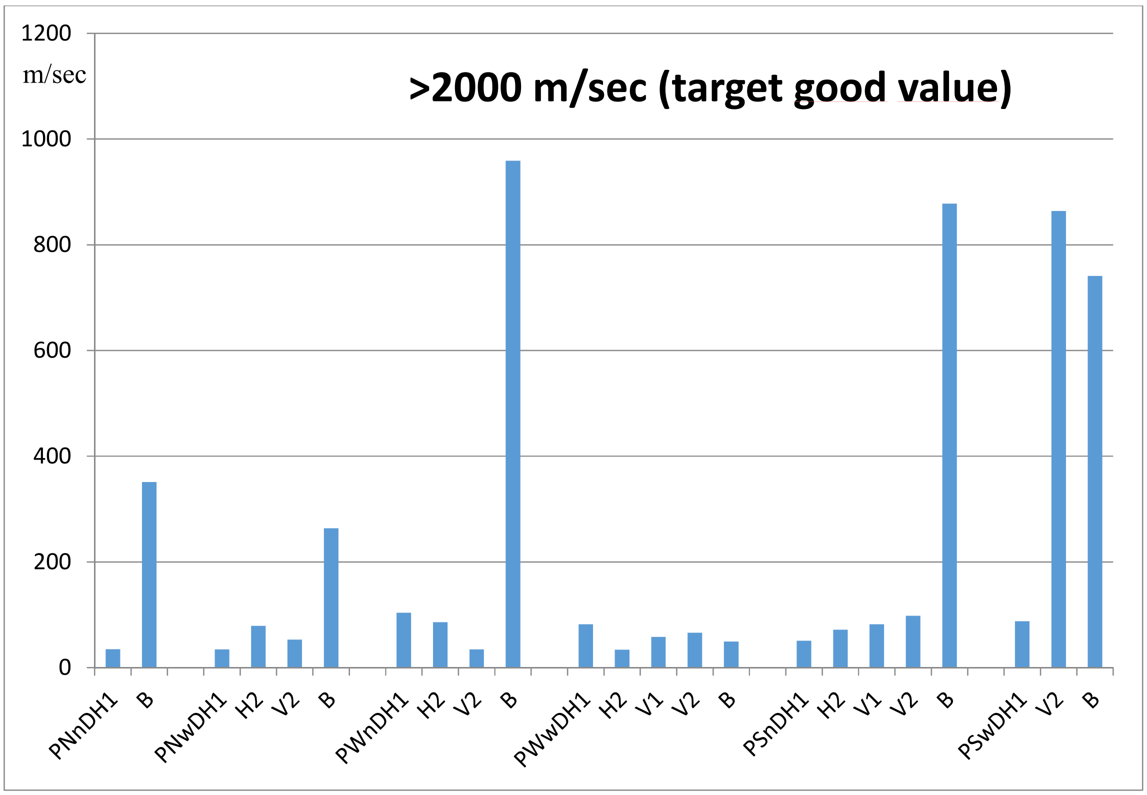
Source: Prof. Salvatore Russo, IUAV, 2015

From the interpretation of this graph we can suggest the following consideration. The graph is related only to mechanical behavior of the bricks and not to that of the masonry which consists of bricks and mortar. But, it means that the value of masonry – even if not tested – can be expected to be less than the value of bricks indicated in the graph. Referring to current literatures the recorded values are all lower than that measured in generic old brick-mortar masonry in good state of conservation. In other words, the histogram as a whole confirms that major masonry structural components of this building are in very low level of conservation as well as in the permanent and progressive process of structural decay. The graph also indicates that, as expected, the difference between the compression strength values in the panel without damage and those in the damaged ones is sensitive. Finally, damaged part of the west façade was detected to be the most vulnerable and decayed. In summary, the mean value of the measured compression strength is around 15 MPa which is typical of a deteriorated masonry in needs of restoration requiring more strength, compactness and efficiency of brick-mortar joints. The graph synthesizes the contents of the tables 1-1 to 1-8 in the appendix.

Ultrasonic test

In order to measure the compactness of masonry, we performed ultrasonic test. As was the case of rebound hammer test, we selected two areas for each of north, west and south exterior facades of the main body of the building, one area without obvious damage and another with damage.

The following bar graph indicates the detected velocity through the object brick and joints in each case. Higher velocity means that the target section has better compactness.



<Tendency of velocity around joints and in the brick>

Legend: PN =north façade, PW=west façade, PS=south façade, nD=without damage, wD=with damage, H=horizontal joint, V=vertical joint, B=single brick

Source: Prof. Salvatore Russo, IUAV, 2015

The graph evidences a deep and wide loss of the joint's efficiency between mortar and bricks, both in vertical and horizontal directions. Although the common literature – as indicated in the same graph – requests and defines that acceptable compactness and joint's efficiency must be more than 2000 m/sec in the corresponding value of velocity, the recorded mean value is only around 400 m/sec. Also, all facades of the temple are commonly characterized by very low values of velocity, which means that disaggregation of the joints occurs practically in all the masonry walls investigated. In detail, the worse situation was recorded in the West façade, while the more positive was in the South side. The recorded values identified with "B" symbol, which is related to the single brick, are between 10 to 20 times of the value measured with joints, which also confirms the above general comments. Finally, as expected, the efficiency of the vertical joints is higher than that recorded with horizontal ones which are affected by the dead load. The graph synthesizes the contents of the tables 2-1 to 2-6 in the appendix.

Fig. 48 Test panel no. 4 for which the rebound hammer test was applied three times for each individual brick to test their compression strength, as well as, the ultra-sonic test to determine the compactness of the overall masonry panel.

(*Source*: ©UNESCO/DOA, 2015)

5) Structural evaluation

Investigation by endoscope

For investigating the situation inside of major cracks appeared on the exterior walls of the main body, visual observation was conducted by inserting an endoscope. The following information was obtained by this observation:

Thickness range of the masonry walls was between 120 and 140 cm.

In the case of the main cracks, the depth varies from 18 cm to around 100 cm at different heights from the ground

Width of the main cracks or discontinuities on the exterior and interior faces of the walls varies from 3-5 mm to 82 mm.

Also, we decided to drill a tiny hole on upper part of the north side of the central pillar and another on the north exterior wall of the main body from both sides of the wall. Then, we inserted an endoscope to investigate if there is any cavity space inside of the pillar or the wall. This investigation resulted in the finding that both the pillar and wall structures were solid, at least in the investigated areas. We expected at the same time to observe difference of construction manner or composition of brick masonry between that near the surfaces and in the core area, but we could not get any clear information about this assumption.

Fig. 49 (upper-right), **Fig. 50** (upper-middle), **Fig. 51** (upper-left), **Fig. 52** (lower-left), **Fig. 53** (Lower-middle), **Fig. 54** (lower-right) Photos showing the condition of a crack of Phya-sa-shwe-gu Temple.

(*Source*: Prof. Salvatore Russo, IUAV, 2015)

III-4 Laboratory testing

After a preparatory survey of laboratory equipment available in Myanmar a universal testing machine of GOTECH GT-7001-LS100 was located in the laboratory of the Myanmar Engineering Society (MES) at Hlaing Campus in Yangon. After a thorough assessment of the situation it became clear that the bond test and four-point bending test could not be carried out due to restrictions of existing technical resources. It was also impossible to carry out a testing by making a masonry sample with original bricks and reproduced mortar similar to the one found in the temple. However, with collaboration of MES experts compression tests of the sample bricks that were collected during the on-site investigation (see III-3 On-site investigation) could be carried out in the laboratory at Hlaing campus.

The objective of running the compression test for brick samples was to measure compression strength of bricks collected from monument no. 1249 and ultimately to contribute to the understanding of the strength of masonry of this monument.

In preparation for running the actual compression tests the samples were prepared by extracting cubes from the original bricks. Whenever possible, three cubes were cut from each sample brick at the size of 4-5 cm. The weight of each brick sample cube was noted down, as well as the exact dimensions of the sides of the cube.

Fig. 55 Sample of brick under the machine before the test.

(*Source*: Myanmar Engineering Society, Hlaing University, Yangon, Myanmar, 2015)

The sample brick cubes were numbered with a combination of letters and numbers referring to their location within target monument (see map in section III-3 4)). The samples were thus marked with the following: S: for South façade, N: for North façade, EN: for Entrance Hall, North, TN: for Terrace North side, W: for West façade, ES: for Entrance hall, South.

The compression machine was set in 'control displacement' and *not* 'control load' mode with a velocity between 1/20 to 1/10 mm/sec. Three photographs were taken for each test cube: one before the test, one during the test and one after the test once the sample cube had collapsed.

The person carrying out the test noted down a short description of the type of collapse, i.e. with or without cracks, or crushing phenomena on the sample and their position, as well as the time it took for the collapse to happen.

After each test the related load displacement diagram was saved from the screen showing the data of vertical displacement (x axis) and load (y axis) for each test.

The figures below document the compression tests run for brick samples from temple no. 1249.

Fig. 56 and Fig. 57 show the collapse phase and the correspondent load-displacement curve for a sample from “S” group. **Fig. 58** to **Fig. 67** show in the same way for samples from “N”, “EN”, “TN, “W” and “ES”, respectively.

Fig. 56 (right) Compression test of a brick sample, provenance "S", situation after the collapse

Fig. 57 (below) Compression Test Report showing the load displacement chart test of a brick sample, provenance "S".

(*Source*: Myanmar Engineering Society, Hlaing University, Yangon, Myanmar, 2015)

Myanmar Engineering Society

Special Project Committee

MES Building Hlaing Universities Campus,
Hlaing Township, Yangon, Myanmar.

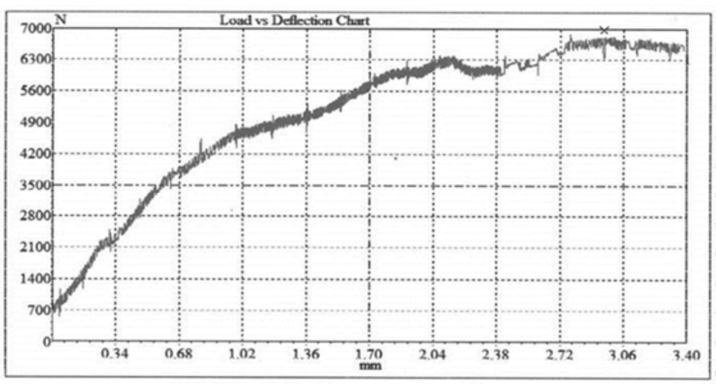
Tel : (95-1) 519673 ~ 6 Fax : (95-1) 519681 Email : mes@mptmail.net.mm

Material : Brick
Samples : S7-4
Customer's Name : UNESCO
Project Name : Bagan Pagoda
Standard : ASTM

Date : 22-09-2015
Report No :

COMPRESSION TEST REPORT

Test No.	Width mm	Thickness mm	Speed mm/min	Max. Load kN	Compression Strength N/mm²
1	52.70	38.94	0.5	6.98	3.4
---	---	---	---	---	---
---	---	---	---	---	---
---	---	---	---	---	---
---	---	---	---	---	---



Tested by
Sign :
Name :

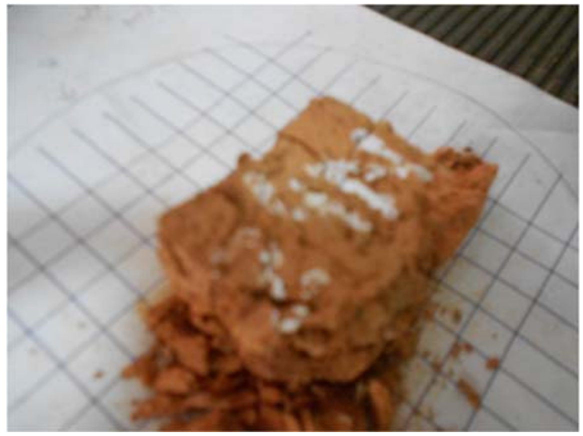
Approved by
Sign :
Name :

Received by
Sign :
Customer's Name :

Fig. 58 (right) Compression test of a brick sample, provenance "N", situation after the collapse.

Fig. 59 (below) Compression Test Report showing the load displacement chart test of a brick sample, provenance "N".

(*Source*: Myanmar Engineering Society, Hlaing University, Yangon, Myanmar, 2015)



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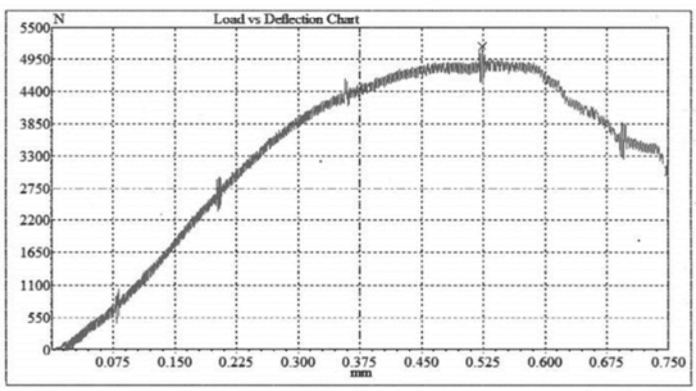
Tel : (95-1) 519673 ~ 6 Fax : (95-1) 519681 Email : mes@mptmail.net.mm

Material : Brick
Samples : N4-3
Customer's Name : UNESCO
Project Name : Bagan Pagoda
Standard : ASTM

Date : 23-09-2015
Report No :

COMPRESSION TEST REPORT

Test No.	Width mm	Thickness mm	Speed mm/min	Max. Load kN	Compression Strength N/mm²
1	38.11	37.09	0.5	5.17	3.7
---	---	---	---	---	---
---	---	---	---	---	---
---	---	---	---	---	---
---	---	---	---	---	---



Tested by
Sign :
Name :

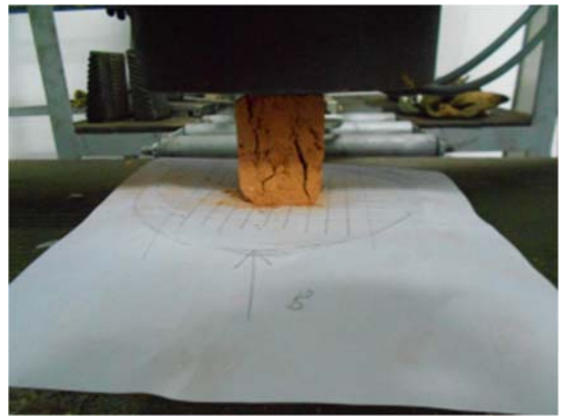
Approved by
Sign :
Name :

Received by
Sign :
Customer's Name :

Fig. 60 (right) Compression test of a brick sample, provenance "EN", situation after the collapse.

Fig. 61 (below) Compression Test Report showing the load displacement chart test of a brick sample, provenance "EN".

(*Source*: Myanmar Engineering Society, Hlaing University, Yangon, Myanmar, 2015)



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Date : 07-09-2015
Report No : -

Material : Brick
Samples : En1-7
Customer's Name : UNESCO Co.,Ltd
Project Name : Bagan Pagoda
Standard : ASTM

COMPRESSION TEST REPORT

Test No.	Width mm	Thickness mm	Speed mm/min	Max. Load kN	Compression Strength N/mm²
1	41.66	35.06	0.5	1.18	0.8
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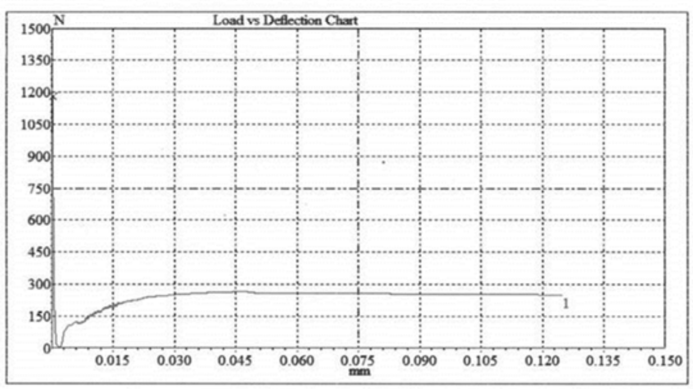


Tested by
Sign :
Name :

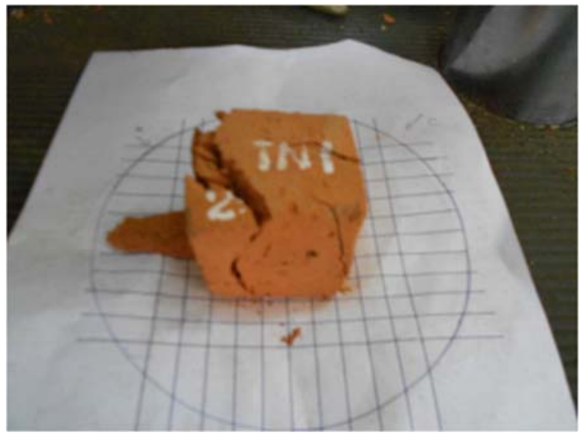
Approved by
Sign :
Name :

Received by
Sign :
Customer's Name :

Fig. 62 (right) Compression test of a brick sample, provenance “TN”, situation after the collapse.

Fig. 63 (below) Compression Test Report showing the load displacement chart test of a brick sample, provenance “TN”.

(*Source*: Myanmar Engineering Society, Hlaing University, Yangon, Myanmar, 2015)



Myanmar Engineering Society

Special Project Committee

MES Building Hlaing Universities Campus,
Hlaing Township, Yangon, Myanmar.

Tel : (95-1) 519673 ~ 6 Fax : (95-1) 519681 Email : mes@mptmail.net.mm

Material : Brick
Samples : TN3-1
Customer's Name : UNESCO Co.,Ltd
Project Name : Bagan Pagoda
Standard : ASTM

Date : 08-09-2015
Report No :

COMPRESSION TEST REPORT

Test No.	Width mm	Thickness mm	Speed mm/min	Max. Load kN	Compression Strength N/mm²
1	46.03	47.55	0.5	8.99	4.1
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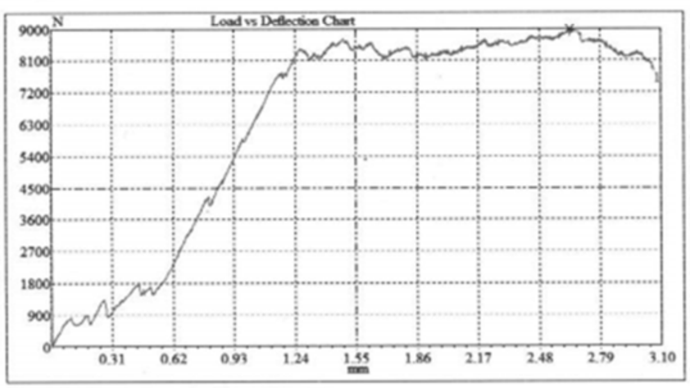

Tested by
Sign :
Name :

Aprroved by
Sign :
Name :

Received by
Sign :
Customer's Name :

Fig. 64 (right) Compression test of a brick sample, provenance "W", situation after the collapse.

Fig. 65 (below) Compression Test Report showing the load displacement chart test of a brick sample, provenance "W".

(*Source*: Myanmar Engineering Society, Hlaing University, Yangon, Myanmar, 2015)

Myanmar Engineering Society
Special Project Committee
MES Building Hlaing Universities Campus,
Hlaing Township, Yangon, Myanmar.
Tel : (95-1) 519673 ~ 6 Fax : (95-1) 519681 Email : mes@mptmail.net.mm

Material : Brick
Samples : W3A
Customer's Name : UNESCO
Project Name : Bagan Pagoda
Standard : ASTM

Date : 24-09-2015
Report No :

COMPRESSION TEST REPORT

Test No.	Width mm	Thickness mm	Speed mm/min	Max. Load kN	Compression Strength N/mm²
1	54.86	45.77	0.5	6.33	2.5
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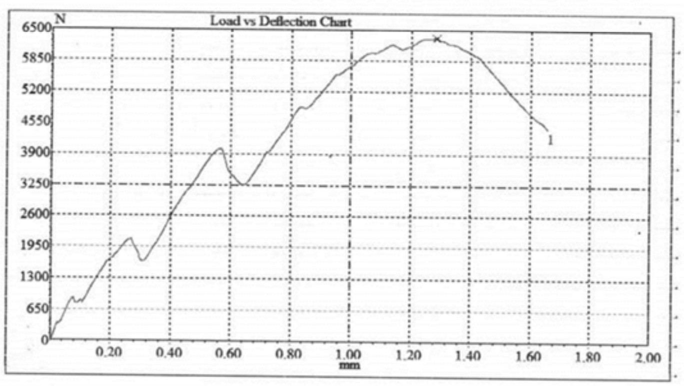


Tested by
Sign :
Name :

Approved by
Sign :
Name :

Received by
Sign :
Customer's Name :

Fig. 66 (right) Compression test of a brick sample, provenance “ES”, situation after the collapse.

Fig. 67 (below) Compression Test Report showing the load displacement chart test of a brick sample, provenance “ES”.

(*Source*: Myanmar Engineering Society, Hlaing University, Yangon, Myanmar, 2015)

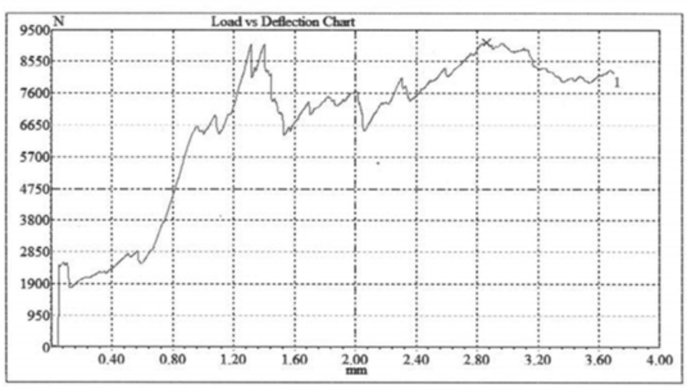
Myanmar Engineering Society
Special Project Committee
MES Building Hlaing Universities Campus,
Hlaing Township, Yangon, Myanmar.
Tel : (95-1) 519673 ~ 6 Fax : (95-1) 519681 Email : mes@mptmail.net.mm

Material : Brick
Samples : ES1-2
Customer's Name : UNESCO Co.,Ltd
Project Name : Bagan Pagoda
Standard : ASTM

Date : 07-09-2015
Report No : -

COMPRESSION TEST REPORT

Test No.	Width mm	Thickness mm	Speed mm/min	Max. Load kN	Compression Strength N/mm²
1	42.35	41.47	0.5	9.11	5.2
---	---	---	---	---	---
---	---	---	---	---	---
---	---	---	---	---	---
---	---	---	---	---	---



Tested by hnin
Sign : hnin
Name : hnin

Aprroved byhnin
Sign : hnin
Name : hnin

Received by
Sign :
Customer's Name :

Generally speaking, the above **Fig. 56** to **Fig. 67** can be analyzed to show a common feature. Firstly, all of the photos show a tendency of multi-fractural collapse (photo of **Fig. 64** is the most representative example) and not in a way with a single or very few lines of break; this means that all of the tested bricks were already damaged considerably by natural decay, although the extent was different from a provenance to another.

All of the experimental load displacement curves appear, unfortunately, to be influenced by the inaccuracy in producing a cube-sample. The maximum levels of loads are not corresponding to the final values of displacement, which is another confirmation of the too much heterogeneity of the results derived from the insufficient accuracy and the decay of the bricks. Some good and positive results are shown in **Fig. 56** to **Fig. 59**, but curves in **Fig. 62** to **Fig. 67** are characterized by unexpected steps of charge and sudden loss of charge before reaching the final phase of softening. **Fig. 60** and **Fig. 61** shows a too low value of load.

Analysis of the obtained data resulted in the following conclusion regarding brick samples of the target monument:

- very low values of compression strength
- experimental load displacement curves were too much influenced by the initial assessment of the machine
- unexpected high brittle behavior which exceed the natural tendency of the brick
- very high level of material decay
- presence of water/moisture inside each brick sample, which strongly affected and permanently compromised the mechanical performance
- inaccurate dimensioning of each cut influenced all the performance
- high dispersion of value depending on the provenance
- low value of maximum load depending on the provenance
- not always reliable experimental curves

The obtained compression values of bricks could be utilized to determine the expected compression value of the masonry. Though it is not common or exactly proper way, a kind of deduced value for masonry can be estimated from the brick even if in absence of any information about the mortar, for which conversion tables are already available. However, it must be emphasized that, for the case of such old construction like the investigated temple, to test a masonry sample, not only the bricks, are strictly required. More generally, the compression strength of masonry is influenced also by other factors as well as the boundary conditions, such as the setting and drying time of the mortar and the precision in the dimensions of the sample.

III-5 Analysis and assessment

The following tables show how the observed cracks on the structure are diagnosed, together with examples of each symptom seen on this temple.

Where Generally	How	Meanings	Where in the Temple 1249
Wall (without interventions)	Vertical	Vertical bending	North Side (Partially) Between vestibule and main body
	Horizontal	Horizontal bending	
	Diagonal	Reached shear strength	North and West Side Interior between vaults
		Differential vertical displacement of foundations	North side
		Consequence of horizontal actions	
	Two diagonal around a corner (favorite by windows)	Growing collapse mechanism of the corner and discontinuity than the covering: due to horizontal load and vertical depression	North and West side
	«X» shape	Effect of earthquake, cyclic action	
	Pass only through mortar	Less level of the stresses	North side
	Pass also through bricks	Higher level of stresses	West Side
	Start from holes/windows	Caused by lateral load and due to the intrinsic vulnerability generated by windows/holes	North, west and South side

Where Generally	How	Meanings	Where in the Temple 1249
Wall (without interventions)	Extended and with crack width larger on the top than the bottom	Out of plane-rocking	North and West side around the corner North and West side in the interior
	Extended but with similar width	In plane kinematism	South side Interior South side
Wall (with interventions)	Between new masonry and older masonry	No correct intervention; a larger action is needed	North side partially
	In the new masonry	Under-dimensioned and not sufficient intervention	
Column/ pillar	Vertical	Reached bearing capacity	Short columns inside between cells
	Horizontal	Very rare, close to collapse	Short columns inside between cells
	Diagonal	Differential vertical displacement of foundations	Short columns inside between cells
		Consequence of horizontal actions	
		Effect of earthquake, cyclic action	
	Vertical in the brick	Consequence of vertical load	Short columns inside between cells
	Vertical in the mortar with «step shape»	Consequence of vertical load combined with lateral component of load	Short columns inside between cells

Source: Prof. Salvatore Russo, IUAV, 2015

Local failure - even though in limited area- around the northwest corner of the main body (between two diagonal cracks identified as N3 and W1) is imminent as well as those around some windows, especially on the north and west sides.

Major cracks are growing, as expected, both exterior and interior sides. The main cracks and discontinuities are deeper at least than half of the wall thickness. They are resulted from the progressive material decay and the negative interaction with displacements induced by too soft soil, which consequently could not stand properly for the last earthquake. Some more recent local interventions/restorations in an inappropriate way also affected the masonry walls. The expected shear strength in the plane of masonry is almost lost.

The monument appears depressed in the ground, and general and local displacements are still in action.

An abundance of holes in the wall, such as windows and niches, even generates a rocking mechanism which can be assumed as typical in the monumental structures in Bagan.

Presence of the corner towers on top of the covering increases horizontal stress supported by the three external walls (except the one connected by the entrance hall) and above all by the stiffness capacity located in the corners.

Analysis of the experimental results from the on-site investigations indicates that the mechanical joints, both vertical and horizontal, between brick and mortar are generally very poor or absent. The parts characterized by good joints are very few and the masonry is not homogeneous any more. Residual compression strength of the bricks are low and with high level of dispersion

The only reason why many monuments similar to this temple still stay right is owing to their massiveness and the fact that at the moment all loads are vertical due to gravity. Any unfortunate next earthquake will be fatal for all temples in a similar state to the 1249.

III-6 Recommendation

The results presented in the previous section III-5 evidenced the presence of important cracks in term of length, width and depth. Particularly along the more significant cracks the width measure is higher on the top than the bottom. It means that there is a translation in the plane of masonry wall in correspondence of where the crack has been detected, combined also rotational displacements. Besides, the variation in the width along the depth (so in the cross section or thickness of each wall) is a confirmation that some parts of walls are turning out than their original position. On the basis of all that said, the following consideration can also be proposed.

Analysis of the mechanical efficiency between the walls and roofs should be performed.

Walking around this building should be prohibited, in particular along the external walls of its main body.

Urgent temporary support should be installed to the external walls of the main body. This is strongly suggested to save all the box-structure of the temple and then to conserve the identity of the monument. The supports should passively and not actively restrain the three facades of the main body.

The priority is not to carry out an immediate **restoration** but above all to avoid **first collapse** and to **limit the collapses**. From this viewpoint, it is recommended to start as soon as possible a continuous monitoring on the progress of structural degradation, such as cracks and displacements. Wireless monitoring system could be an effective means, if available, to monitor the condition of a structure like this case without electric supply or frequent patrol.

Appendix

1. Results of rebound hammer test on pilot monument
2. Results of ultrasonic test on pilot monument
3. S-Card

1. Results of rebound hammer test

1-1 Short columns

Location	Brick	Rebound index(R.I.)	R.I. Mean value	Deduced strength (Kg/cm^2)	Dispersion (Kg/cm^2)
East façade					
	1	30, 25, 31	28,7	220	61
	2	16, 24, 14	18	/	/
	3	19, 20, 20	19,7	/	/
	4a	20, 21, 25	22	128	49
	4b	20, 16, 19	18,3	/	/
	5	19, 23, 16	19,3	/	/
Mean Value			21	58	18,3
North façade					
	1	29, 28, 30, 32, 29, 27,30, 26, 28 27, 28, 27	28,42	220	61
	2	29, 26, 32, 28, 21, 19,32, 30, 32, 26, 23, 20	26,5	190	57
	3	19, 22, 23, 24, 25 31, 29, 27, 18, 27, 26	24,64	165	53
	4	30, 25, 26, 24, 20, 22,19, 24, 21, 28, 15, 22	23	140	50
	5	32, 35, 36, 17, 18, 23,22, 27, 25	26,11	180	56
	6	29, 28, 29, 26, 25, 30	27,8	210	60,5
Mean Value			25,07	184,2	56,25
West façade					
	1	27, 31, 27 29, 33, 39	31	240	62
	2	23, 23,16 30, 42, 33, 24	27,28	200	60
	3	20, 25, 24 17, 26, 19,18	21,28	120	48
	4	24, 26, 29 13, 17, 11	20	100	45
	5	21, 25, 24 34, 33, 36	28,83	220	61
	6	31, 32, 40	34,3	400	70
Mean Value			27,15	213,33	57,7
South façade					
	1	29, 31, 31, 21, 19, 18	24,83	165	53
	2	30, 29, 23, 21, 20, 19	23,67	150	51
	3	29, 26, 27, 30, 31, 21, 27	27,28	205	60,5
	4	13, 19, 23, 19, 25, 23	20,33	105	46,5
	5	13, 26, 28, 20, 19, 22	21,33	120	48
Mean Value			23,49	149	51,8
GLOBAL			24,17	151,13	45,26

1-2 Central pillar

Location	Brick	Rebound index(R.I.)	R.I. Mean value	Deduced strength (Kg/cm^2)	Dispersion (Kg/cm^2)
South					
	1	26, 21, 30	25,67	180	57
	2	34, 27, 27	29,33	235	61,5
	3	33, 23, 34	30	240	62
	4	24, 21, 23	21,67	120	48
	5	15, 19, 11	15	/	/
	6	10, 0, 32	14	/	/
	7	28, 15, 20	21	115	48
	8	31, 20, 30	27	200	60
Mean value			22,95	136,25	42,06
West					
	1	20, 32, 28	26,67	190	58,5
	2	34, 30, 27	30,3	250	62,5
	3	20, 23, 25	22,67	135	52
	4	34, 34, 17, 25	27,5	207	60,3
	5	34, 27, 32	31	258	63
	6	24, 12, 20, 24	20	100	45
	7	18, 28, 23	23	140	51
	8	22, 0, 10, 36	17	/	/
Mean value			24,76	160	49,03
GLOBAL			23,85	133,12	45,54

1-3 North façade without damage

Layer	Brick	Rebound index(R.I.)	R.I. Mean value	Deduced strength (Kg/cm^2)	Dispersion (Kg/cm^2)
I	1	36, 36, 32	34,7	315	65,8
	2	32, 34, 28, 28	30,5	250	62,5
	3	34, 38, 34	35,3	325	66,3
Mean value			33,2	285	64,2
II	4	29, 24, 28	27	195	60,0
	5	32, 32, 30	31,3	255	62,8
	6	28, 32, 28	29,3	230	61,5
	7	26, 28, 32	28,7	220	61,0
Mean value			29,1	225	61,5
III	8	36, 34, 34	35	320	66
	9	34, 32, 32	32,7	265	63,2
	10	35, 40, 37	37,3	360	68
	11	27, 28, 24	26,3	185	56
Mean value			32,7	280	64
IV	12	40, 34, 36	36,7	345	67,5
	13	35, 36, 35	35,3	322	66,5
	14	26, 24, 29	26,3	185	56
	15	35, 40, 42	39	395	69,7
Mean value			34,3	310	65,5
V	16	22, 16, 16	18	/	/
	17	22, 22, 20	21,3	120	48
	18	32, 34, 36	34	300	65
	19	28, 31, 32	30,3	245	61,5
Mean value			25,9	180	55
VI	20	32, 36, 36	34,7	318	65,8
	21	30, 32, 36	32,7	280	64
	22	30, 32, 32	31,3	260	63
Mean value			29,5	240	62
GLOBAL			30,7	255	62,5

1-4 North façade with damage

Layer	Brick	Rebound index(R.I.)	R.I. Mean value	Deduced strength (Kg/cm^2)	Dispersion (Kg/cm^2)
I	1	42,30,27	33	282	64,2
	2	34,40,29	34,3	310	65,5
	3	28,22,23	24,3	160	55
	4	30, 25, 22	25,7	180	58
Mean value			29,3	240	62
II	5	22, 22, 26	23,3	150	52
	6	36, 38, 39	37,7	360	68
	7a°	29, 0, 0	9,7	/	/
	7b	20, 26, 30	25,3	175	54
	8	26, 28, 30	28	218	60,8
	9	26, 34, 49	36,3	340	62
Mean value			26,7	190	58
III	10	38, 34, 40	37,3	365	38,5
	11	39, 39, 32	36,7	345	67,5
	12a°	22, 28, 26	25,3	175	54
	12b	16, 21, 25	20,7	115	48
	13	19, 22, 14	18,3	/	/
	14	18, 31, 18	22,3	130	50
Mean value			26,8	195	58
IV	15a°	18, 14, 18	16,7	/	/
	15b	16, 16, 16	16	/	/
	15c	26, 24, 28	26	180	56
	16	36, 36, 38	36,7	350	67,5
	17	28, 30, 29	29	230	61,5
	18	27, 28,27, 34	29	230	61,5
	19	28, 32, 28	29,3	235	62
Mean value			28,9	230	61,5
V	20	24, 20, 22	22	125	48
	21	36, 16, 26	26	180	56
	22	28, 32, 33	31	258	62,8
	23	28, 26, 30	28	218	60,8
Mean value			26,7	190	58
VI	24	26, 27, 27	26,7	190	58
	25°a	30, 29, 32	30,3	242	62,2
	25b	22, 24, 28	24,7	170	55
	26	29, 29, 28	28,7	228	61
	27	25, 30, 22	25,7	178	54
	28	38, 22, 22	27,3	205	60,2
	29	36, 35, 35	35,3	322	61,2
Mean value			28,4	220	61
GLOBAL			27,8	210,8	59,75

1-5 West façade without damage

Layer	Brick	Rebound index(R.I.)	R.I. Mean value	Deduced strength (Kg/cm^2)	Dispersion (Kg/cm^2)
I	1	18,22,20	20	100	45
	2 a°	26,29,26	27	190	58
	2b	26,20,16	20,7	114	48
	3	30,30,24	28	215	60,8
	4	26,27,38	30,3	245	62,3
Mean value			25,2	175	59
II	5	30,29,28	29	225	61,5
	6	27,27,27	27	200	60
	7	36,33,31	33,3	290	64,5
	8	30,30,28	29,3	235	61,8
Mean value			29,7	238	62
III	9	34,12,23	23	140	50
	10	26,25,23	24,7	165	55
	11	30,26,30	28,7	220	61
	12	24,24,27	25	175	57
Mean value			25,3	176	57,5
IV	13	15,20,19	18	/	/
	14	28,32,39	33	283	64,2
	15	29,32,39	33,3	290	64,5
	16	32,31,31	31,33	260	63
Mean value			28,9	225	61,5
V	17	33,32,27	30,7	250	62,5
	18	36,36,30	34	300	65
	19	29,27,29	28,3	220	61
	20	22,20,19	20,3	110	48
Mean value			28,3	220	61
VI	21	26,27,19	24	158	53
	22	30,27,33	30	240	62
	23	38,36,35	36,3	360	67
	24	25,28,25	26	180	57
Mean value			29,1	225	61,5
GLOBAL			27,75	204,8	60,42

1-6 West façade with damage

Layer	Brick	Rebound index(R.I.)	R.I. Mean value	Deduced strength (Kg/cm^2)	Dispersion (Kg/cm^2)
I	1	27,22,22	23,7	155	53
	2	30,29,19	26	180	58
	3	28,25,23	25,3	175	57
	4a°	11,11,11	11	/	/
	4b	12,0,0,10	5,5	/	/
	5	11,20,19	16,7	/	/
	6	22,20,24	22	130	49
Mean value			18	/	/
II	7	33,29,19	27	200	60
	8	19,17,14	16,7	/	/
	9a°	0,0,0	0	/	/
	9b	1,10,1	4	/	/
	10a°	10,15,0,0	6,25	/	/
	10b	24,25,28	25,7	177	57,5
Mean value			12,9	/	/
III	11	35,30,17	17,33	/	/
	12	25,29,25	27,33	205	60,5
	13	13,12,14	13	/	/
	14	16,16,16	16	/	/
	15	25,29,25	26,7	190	59
Mean value			21,8	79	48
IV	16	34,39,36	36,3	340	67
	17	14,18,15	15,7	/	/
	18	22,20,11,0	13,25	/	/
	19	20,16,22	19,33	/	/
Mean value			20,5	85	47
V	20	24,22,29	25	170	
	21a°	0,0,0	0	/	/
	21b	11,14,11	12	/	/
	21c	20,25,18	21	115	47,5
	22	27,22,23	24	160	53
Mean value			16,4	/	/
VI	23	25,26,26	25,7	180	57
	24	25,24,24	24,3	160	52,5
	25	12,0,0	4	/	/
	26	16,16,14	15,3	/	/
	27	20,22,26,10	19,5	/	/
	28	17,17,27	20,3	107	47
Mean value			18,26	/	/
GLOBAL			17,97	27,33	15,8

1-7 South façade without damage

Layer	Brick	Rebound index(R.I.)	R.I. Mean value	Deduced strength (Kg/cm^2)	Dispersion (Kg/cm^2)
I	1	37,38,35	36,7	350	67,5
	2	34,31,29	31,3	260	63
	3	20,21,24	21,7	125	48
	4	29,25,29	27,7	208	60,3
	5	29,26,29	28	215	60,8
Mean value			29,06	225	61,5
II	6	33,32,23	29,3	235	61,8
	7	33,33,31	32,3	275	63,8
	8	39,39,39	39	395	69,5
	9	29,29,30	29,3	235	61,8
Mean value			35,18	322	66,2
III	10	29,33,32	31,3	260	63
	11	15,19,19	17,7	/	/
	12	30,34,40	35,3	325	66,4
	13	29,32,30	30,3	245	62,2
Mean value			28,41	220	61
IV	14	33,33,28	31,3	260	63
	15	24,30,28	27,3	202	60,2
	16	35,39,29,26	32,25	275	63,5
	17	24,28,25	25,7	180	58
Mean value			29,38	235	61,8
V	18	31,35,29	31,7	262	63,2
	19	25,31,29	28,3	218	60
	20	33,28,34	31,7	262	63,5
	21	31,32,35	32,7	290	64
Mean value			31,08	265	63,1
VI	22	34,33,23,27	29,25	230	61,8
	23	33,29,30	30,7	255	62,5
	24	31,39,37	36	340	67
	25	27,23,25	25	170	54
Mean value			32,38	278	63,8
GLOBAL			30,91	257,5	62,9

1-8 South façade with damage

Layer	Brick	Rebound index(R.I.)	R.I. Mean value	Deduced strength (Kg/cm^2)	Dispersion (Kg/cm^2)
I	1	12,12,16	13,3	/	/
	2	14,14,14	14	/	/
	3	26,29,23	26	180	57,5
	4	25,24,30	26,7	195	58,7
	5	19,28,30	25,7	179	57,5
Mean value			21,1	115	47
II	6	14,14,16	14,7	/	/
	7	24,29,29	27,3	205	60,2
	8	23,29,20	24	158	53
	9	21,26,20	22,3	130	50,5
	10	25,25,23	24,3	162	55
Mean value			22,5	135	51
III	11	29,26,22	25,7	179	57,5
	12	22,22,28	24	158	53
	13	14,18,19	17	/	/
	14	27,29,28	28	215	60,8
	15	29,28,20	25,7	179	57,5
Mean value			24,1	160	54
IV	16	22,20,16	19,3	/	/
	17	16,36,34	28,7	220	61
	18	31,33,29	31	258	62,8
	19	19,36,31,34	30	240	62
	20	16,21,21	19,3	/	/
Mean value			25,9	180	58
V	21	18,12,16	15,3	/	/
	22	18,14,16	16	/	/
	23	25,31,29	28,3	220	61
	24	30,31,29	30	240	62
	25	28,34,30	30,7	250	62,5
Mean value			24,1	160	54
VI	26	14,22,20	18,7	/	/
	27	26,29,24	26,3	185	58,5
	28	25,32,30	29	225	61,2
	29	10,28,20,25	20,75	115	47,5
Mean value			23,5	150	51,5
GLOBAL			23,53	150	52,58

2. Results of ultrasonic test

2-1 North façade without damage

Location	Number of joints inside	Distance (m)	Transit time of sonic wave (microsecond)	Measured velocity (m/sec)
H1-horizontal joint	1	0,283	269,8	325
H2-horizontal joint type 1	2	0,452	/	/
V1-vertical joint type 2	4	0,22	/	/
V2-vertical joint	5	0,263	/	/
B-brick	II Layer	0,305	267,5	351

2-2 North façade with damage

Location	Number of joints inside	Distance (m)	Transit time of sonic wave (microsecond)	Measured velocity (m/sec)
H1-horizontal joint	2	0,342	9850	34,7
H2-horizontal joint type 1	1	0,282	3560	79,2
V1-vertical joint type 2	4	0,264		
V2-vertical joint	5	0,318	5300	53,05
B-brick	I Layer	0,26	986	263,7

2-3 West façade without damage

Location	Number of joints inside	Distance (m)	Transit time of sonic wave (microsecond)	Measured velocity (m/sec)
H1-horizontal joint	1	0,302	3483	104
H2-horizontal joint type 1	2	0,60	6933	86
V1-vertical joint type 2	4	0,235		
V2-vertical joint	5	0,30	8700	34,5
B-brick	V Layer	0,374	390,5	959

2-4 West façade with damage

Location	Number of joints inside	Distance (m)	Transit time of sonic wave (microsecond)	Measured velocity (m/sec)
H1-horizontal joint	2	0,4	4871	82
H2-horizontal joint type 1	1	0,25	7285	34
V1-vertical joint type 2	4	0,205	3500	58
V2-vertical joint	5	0,28	4222	66
B-brick	V Layer	0,347	7008	49,51

2-5 South façade without damage

Location	Number of joints inside	Distance (m)	Transit time of sonic wave (microsecond)	Measured velocity (m/sec)
H1-horizontal joint	1	0,25	7000	52
H2-horizontal joint type 1	2	0,574	8000	71,75
V1-vertical joint type 2	4	0,283	3700	82,03
V2-vertical joint	5	0,28	2850	98,24
B-brick	VI Layer	0,359	409	878

2-6 South façade with damage

Location	Number of joints inside	Distance (m)	Transit time of sonic wave (microsecond)	Measured velocity (m/sec)
H1-horizontal joint	1	0,253	1864	88,34
H2-horizontal joint type 1	2	0,45	/	/
V1-vertical joint type 2	4	0,222	/	/
V2-vertical joint	5	0,28	324	864
B-brick	V Layer	0,255	364	741

STRUCTURE RAPID CONDITION ASSESSMENT CARD **BAGAN, REPUBLIC OF THE UNION OF MYANMAR** Version8 03/16	**Monument Number/Name:**

1. IDENTIFICATION OF MONUMENT & DETAILS OF INSPECTION

Name of Monument	**Monument Number**	**Main Entrance Orientation**

Type of Monument

☐ Temple ☐ Stupa ☐ Monastery ☐ Underground Structure ☐ Archaeological Element / Surrounding Structure (e.g. wall, gate) ☐ Other (specify)

Location Description (include locality number if known)

Location GPS Coordinates (Lat/Long) and Elevation (Above Sea Level)

Topography

☐ Plain ☐ Elevated ground ☐ Slope ☐ Depression ☐ Hilltop ☐ Valley ☐ Other (specify)

Previous Intervention	**Previous Investigation and Report**
☐ Conservation (structural) ☐ Conservation (chemical) ☐ Re-plastered/whitewashed ☐ Restoration ☐ Reconstruction ☐ Excavation ☐ Other (specify) Date of intervention (if known) and Description:	☐ Documentation ☐ Field Observation ☐ Survey ☐ Technical Report ☐ Other (specify) Description:
Inspector (s) Name	**Inspector (s)' Institution**
Inspection Date	**Weather Condition on Inspection Date**
	☐ Raining ☐ Not Raining

Type of Inspection

☐ Regular Inspection ☐ Emergency Condition Assessment ☐ Rainy Season Inspection

Remarks (in case of emergency assessment):

3. LEVEL OF PRIORITY AND RECOMMENDED ACTIONS

Monument Grading	**Value factors** (taken into account for prioritization)
☐ Grade I ☐ Grade II ☐ Grade III ☐ No Grade	
Overall Severity Magnitude of Observed Degradations	**Overall Extent of Observed Degradations**
☐ High ☐ Medium ☐ Low	☐ Partial to Total ☐Partial ☐ Limited

Overall Condition Rating – Current (based on severity and magnitude of overall degradations)

☐ Very Bad ☐ Bad ☐ Poor ☐Fair ☐ Good

Remarks:

Overall Risk Rating

☐ Very High ☐ High ☐ Medium ☐ Low ☐ Very Low

Remarks:

Immediate Action(s) Needed

☐ Vegetation clearance ☐ Waterproofing ☐ Drainage improvement ☐ Partial masonry repair
☐ Locking gate and fencing ☐ Other (specify):

Action(s) Needed

☐ Emergency action needed ☐ In depth condition assessment ☐ Mural and decorated surfaces assessment ☐ Further research
☐ Minor Conservation ☐ Relocate development proposal ☐ Improve previous restoration
☐ No action needed (stable condition) ☐ Other (specify):

Level of Overall Priority (to undertake action(s) needed)

☐ Urgent ☐ High ☐ Medium ☐ Low

Remarks:
Safety concerns (danger for visitors)
☐ Yes ☐ No If 'yes' please specify:
Recommended Future Monitoring Schedule
☐ Every month ☐ Every 6 months ☐ Every year ☐ After each rainy season ☐ Every 2 years ☐ 3-5 years ☐ Other (specify)

STRUCTURE RAPID CONDITION ASSESSMENT CARD **BAGAN, REPUBLIC OF THE UNION OF MYANMAR** Version8 03/16	**Monument Number/Name:**

2. CONDITION ASSESSMENT

Structure (TEMPLE and MONASTERY)

☐ Ground floor ☐ 1st floor ☐ 2nd floor ☐3rd floor

EXTERIOR				A	B	C	D	E	F	G	H					
				Collapse	Deformation	Break	Crack	Deterioration/ Decay	vegetation	Poor Drainage	Other	Damages Severity (H, M, L)	Damage Extent (Size)	Clarify the locations Not Inspected	Photo Number	Description/Remarks
Exterior		Spire	E													
			S													
			W													
			N													
	1	Square Tower/Circular Dome/Tower	E													
			S													
			W													
			N													
	2	Corner Tower/Stupa	E													
			S													
			W													
			N													
	3	Roof	E													
			S													
			W													
			N													
	4	Terrace (1,2,3), wall	E													
			S													
			W													
			N													
	5	Main Body (cornice, wall, base)	E													
			S													
			W													
			N													
	6	Entrance Hall	E													
			S													
			W													
			N													
	7	Porch	E													
			S													
			W													
			N													
	8	Lateral Porch	E													
			S													
			W													
			N													

Degradation Observed in Immediate Surroundings (i.e. platform, apron, etc.):

STRUCTURE RAPID CONDITION ASSESSMENT CARD BAGAN, REPUBLIC OF THE UNION OF MYANMAR Version8 03/16	Monument Number/Name:

			A	B	C	D	E	F	G	H	I					
INTERIOR			Collapse	Deformation	Break	Crack	Deterioration/ Decay	Vegetation	Poor Drainage	Leak	Other	Damage Severity (H, M, l)	Damage Extent (Size)	Clarify the locations Not Inspected	Photo Number	Description/Remarks
Interior	9	Porch/front door														
		Vault														
	10	Lateral Porch/lateral door														
		Vault														
	11	Vestibule														
		Vault														
	12	Entrance Hall														
		Vault														
	13	Passage														
		Vault														
	14	Corridor (Int or Ext)														
		Vault														
	15	Staircase														
	16	Solid Core														
	17	Shrine / Central Cell														
		Vault														

STRUCTURE RAPID CONDITION ASSESSMENT CARD
BAGAN, REPUBLIC OF THE UNION OF MYANMAR Version8 03/16

Monument Number/Name:

CONDITION ASSESSMENT
Structure (STUPA)

			Orientation	A	B	C	D	E	F	G	H	I	Damage Severity (H,M,L)	Damage Extent (Size)	Clarify the locations Not Inspected	Photo Number	Description/Remarks
				Collapse	Deformation	Break	Crack	Deterioration / Decay	vegetation	Poor Drainage	Leak	Other					
		Spire	E														
			S														
			W														
			N														
	1	Tower/ Dome	E														
			S														
			W														
			N														
	2	Upper Terrace(s)	E														
			S														
			W														
			N														
	3	Corner Stupa	E														
			S														
			W														
			N														
	4	Lower Terrace(s)	E														
			S														
			W														
			N														
	5	Stairway	E														
			S														
			W														
			N														
	6	Base	E														
			S														
			W														
			N														

Degradation Observed in Immediate Surroundings (i.e. platform, apron, etc.):

Other Types of Monuments Underground structure and surrounding elements (e.g. wall and gate)

STRUCTURE RAPID CONDITION ASSESSMENT CARD **BAGAN, REPUBLIC OF THE UNION OF MYANMAR** Version8 03/16	**Monument Number/Name:**

Decorative Elements (e.g. stucco, mural painting, glazed plaque, stone carving, sculpture, statue, flooring, and other decorative elements)

Type of Decorative Element	Location (Architectural Element)	Degradation Type	Damage Severity (CHOOSE: HIGH, MEDIUM,LOW)	Extent (size) of Damage (CHOOSE: TOTAL/ PARTIAL/ LIMITED)	Description	Decorative Surface Assessment Needed: YES or NO	Photo Number

Risk Assessment (based on common threats such as *Animal Impact*, *Earthquake*, *Fire*, *Flood*, *Inappropriate Restoration*, *Pollution*, *Rain*, *Theft/Looting*, *Urban Development*, *Vandalism*)

Potential Threat(s)	Exposure	Related Vulnerability Factors	Risk/Potential Impact	Probability (likelihood)	Severity of potential Impact	Risk Level
				□ High □ Medium □ Low	□ High □ Medium □ Low	□ Very High □ High □ Medium □ Low □ Very Low
				□ High □ Medium □ Low	□ High □ Medium □ Low	□ Very High □ High □ Medium □ Low □ Very Low
				□ High □ Medium □ Low	□ High □ Medium □ Low	□ Very High □ High □ Medium □ Low □ Very Low
				□ High □ Medium □ Low	□ High □ Medium □ Low	□ Very High □ High □ Medium □ Low □ Very Low

Sketch of Monument with location of disturbances; use combination of letters (for kind of degradation) and numbers (for location) assigned to each condition table to locate disturbance.