Report on the Restoration of the East Gate, Ta Nei Temple, Angkor, Cambodia

2019 - 2022

Authority for the Protection and Management of Angkor and the Region of Siem Reap (APSARA)

Tokyo National Research Institute for Cultural Properties (TOBUNKEN)

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Foreword

Angkor, one of the most important archaeological sites (temples and hydraulic structures), represents not only the prosperity and glory of the ancient Khmer civilization under the reign of the Angkorian Kings, but also the history of wisdom shared by all humankind.

Following its inscription on the UNESCO World Heritage Sites List in 1992, the International Coordinating Committee for the Safeguarding and Development of the Historic Site of Angkor (ICC-Angkor) was established to protect and develop it sustainably. Subsequently, a multitude of national and international efforts, spanning diverse areas of expertise, have significantly contributed to the preservation of Angkor, all overseen and coordinated by the APSARA National Authority (APSARA), established in 1995.

Among them, the collaborative project on the Ta Nei Temple between APSARA and Tokyo National Research Institute for Cultural Properties (TOBUNKEN) was initiated in 2001. The project facilitated the capacity building of young staff through diverse joint research programs focused on studying stone deterioration caused by microorganisms, as well as through survey training programs. In 2017, we launched a pilot project for the conservation and sustainable development plan for Ta Nei temple with technical support from TOBUNKEN. Based on this plan, the restoration of the East Gate of Ta Nei temple commenced in 2019 and was completed in 2022. In 2020, the COVID-19 pandemic posed challenges to this joint project: TOBUNKEN team members were unable to work on site during 2020 due to the travel bans, while APSARA staff members continued with onsite reassembling work of the East Gate. Despite these circumstances, online exchanges between both parties were meticulously carried out to ensure that onsite work was not disrupted, which has received tremendous appreciation from the experts of ICC-Angkor.

Finally, I would like to extend my sincere gratitude to everyone who contributed to this milestone the successful restoration of the East Gate. Special appreciation goes to the expert members and field staff for their dedicated efforts to the project. I believe the long-term collaboration in the field of heritage conservation between APSARA and TOBUNKEN will contribute in preserving the significant and distinct value of Ta Nei Temple, as well as the entire Angkor complex. Ta Nei will be integrated into the itinerary of Angkor’ s tourism development in the future.

HANG Peou, Ph.D
Director General,
Authority for the Protection and Management of
Angkor and the Region of Siem Reap

Preface by TOBUNKEN

The appearance of Ta Nei Temple as of the time of its discovery has been well maintained, which is an exceptional case among the ancient monastic complexes located in the centre of Angkor Archaeological site. Its landscape is in an attractive, harmonic co-existence with the Temple ruin and the rich natural environment. While the temple is considered as one of the important temples to have been constructed during the reign of King Jayavarman VII, research on its construction purpose and its entire structure has not been fully conducted. We all look forward to revealing these secrets of the temple.

The Tokyo National Research Institute for Cultural Properties (TOBUNKEN) has been working on the study and conservation of Ta Nei Temple in cooperation with the Authority for the Protection and Management of Angkor and the Region of Siem Reap (APSARA) of the Kingdom of Cambodia since the start of the project in 2001. After joint research in the biological science field and implementation of training programmes for local personnel, TOBUNKEN and APSARA started discussions about the full-scale conservation and sustainable development of this temple itself in 2014, and developed the Conservation and Sustainable Development Plan for Ta Nei Temple in 2017. In the same year, the plan was approved by the International Coordinating Committee for the Safeguarding and Development of the Historic Sites of Angkor (ICC-Angkor).

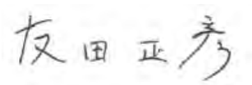
The goals of the Conservation and Sustainable Development Plan for Ta Nei Temple were set to appropriately maintain and conserve its characteristics as a mixed heritage as mentioned above, and simultaneously enable tourists to safely visit and better understand the temple. To achieve these goals, the rehabilitation of the east approach way, which is the temple's original main approach, and the restoration of the East Gate, which is the main building of the east approach way, were positioned among the main measures to be undertaken.

Of the many structures that make up the temple building complex, the East Gate was among the most poorly conserved. The original external appearance was severely damaged and it was not possible to pass through the gate because the roof was collapsed and the walls leaned heavily. On the other hand, the condition of the original materials was comparatively good, and so it was considered that recovery of most of the original features would be possible through careful restoration. In undertaking the restoration of this small building, APSARA strongly hoped to make this restoration project a model case for further conservation and safeguarding for the Angkor complex, as well as for future restoration of other buildings to be conducted under its own initiative and through its own efforts. In response to this strong will of APSARA, TOBUNKEN started the cooperative restoration project under the condition that

TOBUNKEN would continuously provide technical support. Though the restoration started in 2019, it was seriously affected by the unexpected worldwide COVID-19 pandemic. Nevertheless, the restoration was successfully completed by the autumn of 2022. We are proud to have achieved the high-level conservation of its authenticity, which is required as a component of the World Heritage Site, by maximally maintaining the original materials and construction techniques.

This report summarises the background, restoration policies, specific restoration methods, research outcomes, and more for the conservation and safeguarding of the East Gate of Ta Nei Temple. We are confident that this will be beneficial for future research on Ta Nei Temple, and as reference for the general conservation and restoration at Angkor.

Last, but not least, I would like to express my heartfelt appreciation to H.E. Dr. Hang Peou, Director General of the APSARA National Authority, to the APSARA staff, and to the external experts and the international teams working on the Angkor monuments for graciously providing their technical knowledge and sharing their experiences throughout the project, along with my heartfelt gratitude to all of the Cambodian engineers and staff involved for conducting the safe and high-quality restoration work, and to the TOBUNKEN staff for their dedicated engagement in this project.



TOMODA Masahiko
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Cultural Properties

Notes

1. Book content summarises the project "Restoration of the East Gate, Ta Nei Temple, Angkor, Cambodia" implemented as a cooperation project between the Authority for the Protection and Management of Angkor and the Region of Siem Reap (APSARA), and Tokyo National Research Institute for Cultural Properties (TOBUNKEN).

2. The persons in charge of writing are added at the beggining of each manuscript.

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Chapter 2:	TOMODA Masahiko (2.1)
Chapter 3:	KANAI Ken (3.1), KUROIWA Chihiro (3.2)
Chapter 4:	KANAI Ken, ASADA Natsumi, VAR Elif Berna, MARTINEZ Alejandro, PROM Titchhopnnarith, THAI Yamang, DOY Pichjira (4.1-4.2)
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Photos were taken by the author or field staff members of APSARA and TOBUNKEN (except for special remarks).

3. Some articles of this book were reprinted from the previously published report as described below. "*" shows that the original text was modified or added for the reprinting.

Chapter 1 (1.1-1.4):
- Tomoda, M. and Ly, V (eds.). 2019. Technical Cooperation Project for the Conservation and Sustainable Development of Ta Nei Temple, Angkor -Progress Report of 2017 and 2018- , The Authority for the Protection and Management of Angkor and the Region of Siem Reap (APSARA) and Tokyo National Research Institute for Cultural Properties.

Chapter 3 (3.1*), Chapter 4 (4.1-4.2*), Chapter 5 (5.1), Chapter 6 (6.1*):
- Tomoda, M. and Kim, S. (eds.). 2020. Technical Cooperation Project for the Conservation and Sustainable Development of Ta Nei Temple, Angkor -Progress Report of 2019-, The Authority for the Protection and Management of Angkor and the Region of Siem Reap (APSARA) and Tokyo National Research Institute for Cultural Properties.

Chapter 9 (9.1*):
- Tomoda, M. and Kim, S. (eds.). 2021. Technical Cooperation Project for the Conservation and Sustainable Development of Ta Nei Temple, Angkor -Progress Report of 2020-, The Authority for the Protection and Management of Angkor and the Region of Siem Reap (APSARA) and Tokyo National Research Institute for Cultural Properties.

Chapter 1

Conservation and Sustainable Development Plan for Ta Nei Temple

1.1. Overview of Ta Nei Temple

TOMODA Masahiko

Ta Nei is one of the many Buddhist temples built during the reign of King Jayavarman VII. Examining its architectural style reveals that its main part is thought to have been constructed at the end of the 12th century. It is located northwest of the East Baray reservoir, where the artificially canalized Siem Reap River flows from the north through the west of the temple (Figure 1.1.1).

The temple consists of at least three concentric structures (Figure 1.1.2). A laterite terrace lies on top of the West Embankment of the East Baray, from where the approach way extends to the East Gate of the Outermost Enclosure for about 100 m. This Enclosure made with laterite measures 188 m from east to west, and 157 m from north to south, with two gates of sandstone built in the middle of the east and west sides. Inside these gates are Cruciform and Rectangular Terraces that are connected to the Central Complex. On both the north and south sides of the main complex, there is a C-shaped Moat surrounded by stepped walls made of laterite.

The temple proper is surrounded by two galleries. One of its distinctive features is that the Inner Gallery extends to the east and becomes integrated with the Outer Gallery on the side. The Outer Gallery measures 56 m from east to west and 47 m from north to south, and has openings at the four cardinal directions. Although most of the gallery has collapsed and is in a state of considerable ruin, the exterior wall is made of laterite, while the pillars and roof structures are presumably constructed using timber and covered with roof tiles. Inside this gallery, there used to be several sets of statue triads depicting *Buddha Muchalinda*, *Avalokiteśvara* (called Lokesvara in Cambodia), and *Prajnaparamita*; however, only their pedestals remain.

The Inner Gallery is a mixed structure of sandstone and laterite. Of its four Entrance Pavilions, the ones to the north, south, and west are topped with tiered towers. The courtyard surrounded by this gallery measures 38 m from east to west, and 21 m from north to south. Inside this courtyard stands the Central Tower Shrine made of sandstone, with a 15 m high tower, a Library made of laterite to its southeast, and another independent tower shrine of sandstone located where the East Gate of the Inner Gallery would normally have stood. Although the north side of the Central Tower Shrine is connected to the Inner Gallery, this configuration seems to be the result of a later alteration. In addition, many remaining traces, such as holes to insert wooden roof structures, suggest that this temple was used for a long period, with modifications made to it as required.

Ta Nei is smaller in scale when compared to the representative temples in the Angkor region, however, it retains several unique architectural features along with splendid carvings. Moreover, as no full-fledged restoration has been performed here since the rediscovery, the temple retains its ruined scenery amidst the large trees, making this site very attractive for visitors.

1.2. Previous Studies on the Temple

TOMODA Masahiko

Although no clear record of the discovery of Ta Nei has yet been found, E. Aymonier described this temple in terms of its scale, basic composition, and the contents of its inscriptions in the third volume of *'Le Cambodge'* published in 1904. In the third volume of 'Inventaire Descriptif des Monuments du Cambodge' published in

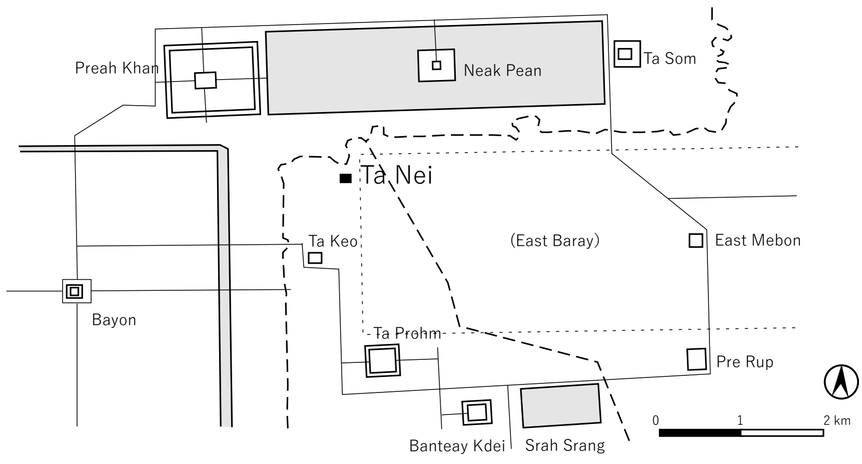


Figure 1.1.1 Location of Ta Nei Temple

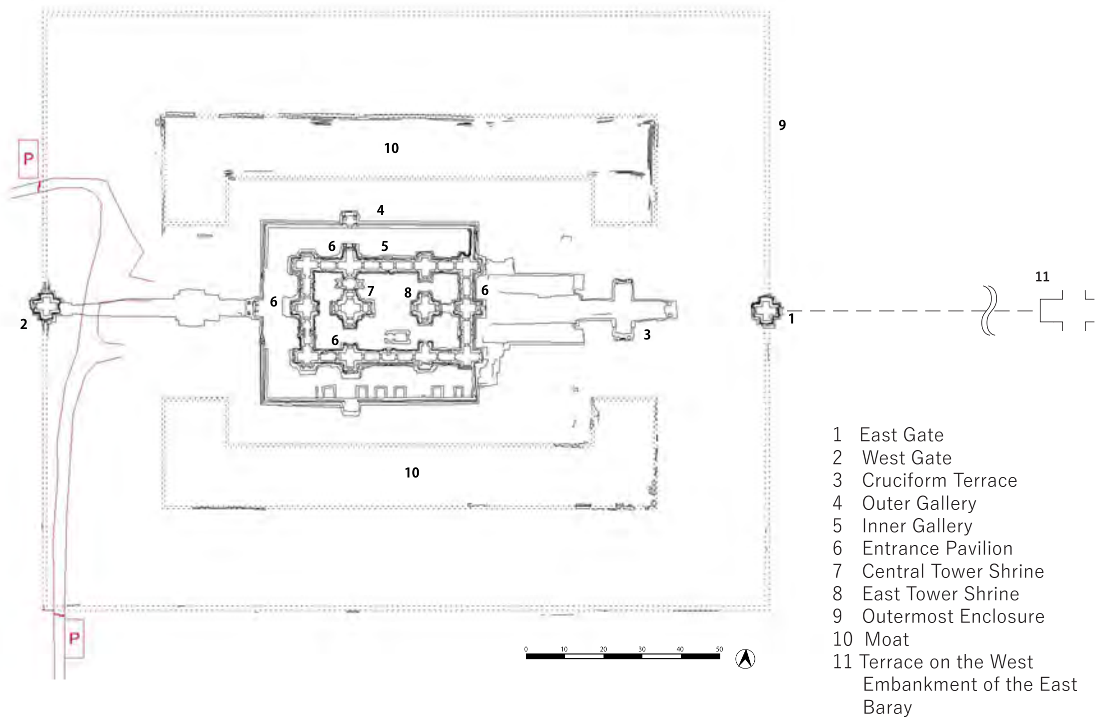


Figure 1.1.2 Ta Nei Temple

1911, E. L. Lajonquiere also explained about its composition, including the Enclosure, and provided a rough plan that was not quite exact. On the other hand, an article printed in “Rapport CA” (Angkor Conservation Report) in the year 1926 reported that a newly opened path connecting to the short circuit finally made this temple accessible for tourists. Despite this, the entire temple area appears to be covered with vegetation until the 1940s when a dam was constructed in its northern vicinity.

The first detailed investigation on Ta Nei was conducted by H. Parmentier in 1940, ever since which its stylistic similarity to Preah Khan has been highlighted by various scholars. Recently, O. Cunin reexamined the chronology of the temple while referring to the results from the magnetic susceptibility measurement of the stone materials ('De Ta Prohm au Bayon' , 2004). This measurement positioned the main temple complex at the same period as the initial stage of Bayon’s construction during the end of the 12th century, and the Enclosure, including the East and West Gates, at a later period corresponding to the second stage of Bayon. Meanwhile, Aymonier already pointed out that the location of Ta Nei could be related to the East Baray; however, no specific correlating factor has been clarified so far.

It seems that H. Marchal, M. Glaize, and some other French conservators conducted archaeological excavation at Ta Nei several times during the 1920s and 1930s. However, as the reports have not yet been published, their handwritten logs must be studied for details. Even today, a trace of excavation can clearly be seen, such as around the West Gate of the Enclosure. Additionally, stone blocks in different areas inside the temple have obviously been moved and rearranged in the past, which suggests that during such work, a substantial amount of the soil above the original surface was removed once. Also, more than twenty sandstone statues collected from Ta Nei have been stored in the Angkor Conservation Office, including those of large standing Dvarapalas.

Some work was done in the past to clear vegetation and reposition the scattered stones in order. However, Ta Nei has never become the target of a full-scale restoration, making it an exception among the major temple ruins that constitute the Angkor Monuments. This has enabled the serene environment amidst the dense forest as well as the ruined scenery to miraculously be maintained at this site. Additionally, being far from the main tourism traffic network, Ta Nei is still less visited than the other monuments. However, the number of visitors to Ta Nei has gradually been increasing in recent years due to rapid growth of tourism to the entire monument group, and because of the progress of the restoration at Ta Prohm, which is famous for its spectacle of gigantic trees encroaching the ruins. Thus, it becomes necessary to take measures for both mitigating the damages to the site conservation and securing the safety of visitors.

1.3. Conservation and Sustainable Development Plan for Ta Nei Temple

MARTINEZ Alejandro

1.3.1 Background of the Conservation and Sustainable Development Plan for Ta Nei Temple

Work on the conservation and sustainable development Plan for the Ta Nei Temple began 2014 onward, when the Tokyo National Research Institute for Cultural Properties (TOBUNKEN) and the Authority for the Protection and Management of Angkor and the Region of Siem Reap (APSARA) began recording and documenting the current condition of the site through photogrammetry and CAD drawings.

Subsequently, a seven-step workflow to draft the plan was developed (Table 1.3.1), with work on steps 1 to 3 (collection of information, analysis of present state and establishment of basic policy) beginning immediately.

In January 2017, a joint TOBUNKEN and APSARA workshop was held at the APSARA headquarters with the purpose of defining the basic policies of the plan. The participants included members of Department of Monument Conservation and Preventive Archaeology, Department of Forest Management, Department of Water Management, and Department of Tourism Management at APSARA, along with Japanese experts. During this workshop, a general agreement was reached regarding the significance and special features of the site, the main objectives for its conservation and sustainable development, and the basic policies required to reach those objectives. The contents of this plan are based on the results of this workshop. The basic outline of the plan was reported during the 28th technical session of International Coordinating Committee for the Safeguarding and Development of the Historic Site of Angkor in June 2017.

Table 1.3.1
Workflow for drafting and implementing the Conservation and Sustainable Development Plan for Ta Nei

STEP 1 Collection and sorting of basic information
▼
STEP 2 Analysis of present state and issues
▼
STEP 3 Establishment of conservation, management and sustainable development policy
▼
STEP 4 Basic planning
▼
STEP 5 Detailed planning
▼
STEP 6 Implementation
▼
STEP 7 Documentation

1.3.2. General principles and zoning

The following general principles were agreed upon as the basis of the plan.

1. In order to retain the natural setting of the ruined remains, the site should be conserved in its current condition as much as possible. Interventions should be undertaken only to the minimum necessary.
2. Further collapse of the buildings should be prevented and visitors' safety should be ensured.
3. Appropriate measures for the presentation and interpretation of the site should be taken in order to improve visitors' understanding of its significance and characteristics.
4. The site should be positioned within its larger archaeological context, while simultaneously providing an ecotourism experience.

Accordingly, it was decided to divide the site into four zones, where different levels of interventions will be conducted (Figure 1.3.1).

A) The Core Zone (central temple compound area, inside the north and south Moats): only minimum interventions (such as shoring with supports and removing or resetting unstable blocks) will be performed to conserve the site in its current condition. Visitor’s routes will be rearranged and vegetation management will be carried out.

B) Entrance / Interpretation Zone (east approach area): partial restoration will be performed in order to improve the readability of the east side as the front side of the temple; interpretation and facilities for visitors will also be implemented.

C) Setting Conservation Zone (area between the Outermost Enclosure and the Moats, especially the west side): vegetation management will be carried out and facilities for maintenance and management of the site will be implemented.

D) Environment Conservation Zone (the temple grounds outside the Enclosure): the natural environment will be conserved without any interventions, except for the access road.

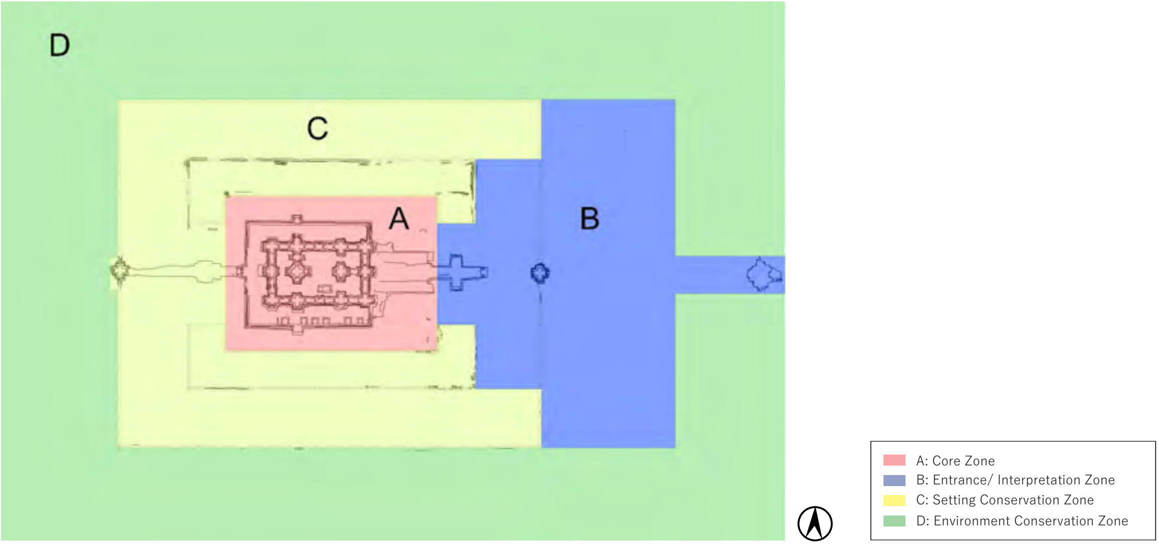


Figure 1.3.1 Zoning

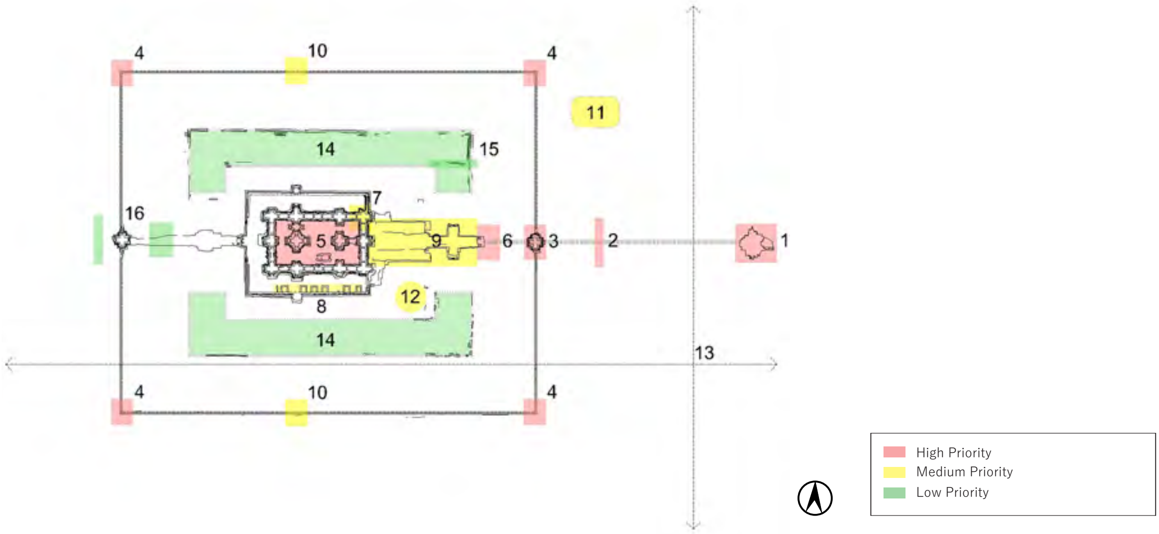


Figure 1.3.2 Archaeological investigation

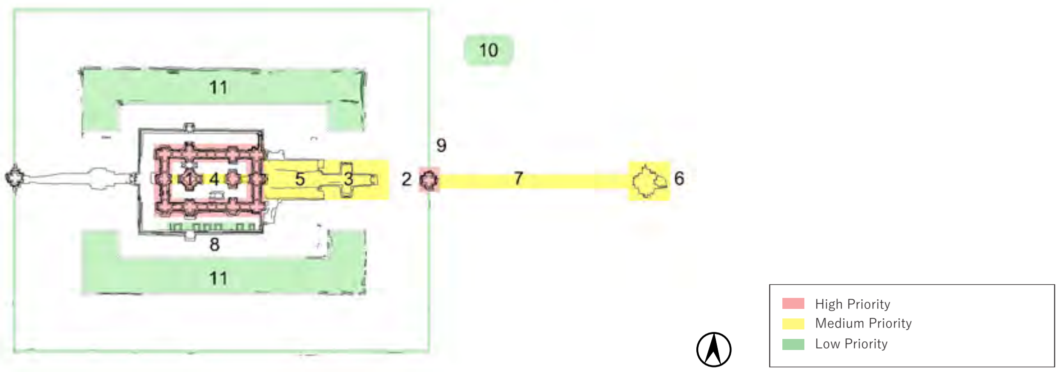


Figure 1.3.3 Conservation intervention

Following this basic policy and zoning method, the work on the site has been performed simultaneously from three interrelated angles: investigation, conservation, and sustainable development.

This section will summarise the priorities of the planned interventions for each of these aspects.

1.3.3. Investigation

Archaeological investigation is required in order to clarify the features of the site, including its relationship with the East Baray and original approach way from the east side, as well as the structure of the Enclosure, most of which is now lost. Additionally, the current condition of the site needs to be recorded, including the positions of the fallen stone blocks. The information obtained through this investigation will be incorporated into the conservation and sustainable development plan, and will help in improving the conservation, presentation, and management of the site.

Archaeological investigation is classified into high priority, medium priority, and low priority, as follows (Figure 1.3.2).

High priority:

1. Terrace on the West Embankment of the East Baray: determining the shape, size, and structure of the Terrace.
2. East approach way (between the East Gate and the Terrace): determining the size and structure of the approach way.
3. East Gate and east side of the Outermost Enclosure: determining the structure of the foundations.
4. Corners of the Outermost Enclosure: determining the limits of the Enclosure.
5. Inner Courtyard: documenting fallen stone blocks.
6. East approach way (between the East Cruciform Terrace and the East Gate): determining the size and structure of the approach way.

Medium priority:

7. Corners of the Inner Courtyard, inside the Inner Gallery: determining the structure of pavement.
8. Outer Gallery (south side): determining the structure of pedestals.
9. East Rectangular Terrace, East Cruciform Terrace: documenting the fallen stone blocks, and determining the structure of the foundations.
10. Outermost Enclosure (north and south side): determining the presence and structure of gates.
11. Northeast Pond: determining the size, shape, and structure.
12. Mound to the south of the eastern Cruciform Terrace: determining the nature of the remains.
13. Boundaries of the temple area: determining the size of the site.

Low priority:

14. Moats: determining the structure of the embankments.
15. North Moat (southeast section): determining construction history and possibility of later extension.
16. West approach way (both sides of the West Gate): determining the presence, structure, and size of the approach way.

1.3.4. Conservation

The priorities of conservation and repair interventions are decided based on the assessment of the current condition of the site. A risk map of the site is being drafted in order to evaluate the level and probable causes of decay at all parts of the site.

Conservation interventions are classified into high priority, medium priority, and low priority as follows (Figure 1.3.3).

High priority:

1. Central Tower Shrine, East Tower Shrine, Inner Gallery, and Outer Gallery: renewal of temporary supports and resetting/removal of unstable stones.
2. East Gate: repair through dismantling and reassembly.

Medium priority:

3. East Cruciform Terrace: repair through dismantling and reassembly.
4. Inner Courtyard: rearrangement of the fallen stones along the central axis.
5. East Rectangular Terrace: vegetation clearance and surface cleaning.
6. Terrace of West Embankment of East Baray: protection and presentation of the remains.
7. East approach way: protection and presentation of the remains.

Low priority:

8. Pedestals on the south side of the Outer Gallery: restoration of one pedestal to its original state, and conservation of the current conditions of the rest.
9. Enclosure: excavation and presentation of the segments on both sides of the East Gate, covering and conservation of the rest of the remains.
10. Northeast Pond: vegetation clearance and improvement of the current condition.
11. Moats: limited vegetation clearance to improve the scenic views of the site.

The rest of the site, including the Outer Gallery, West Terrace, and West Gate, will be conserved in their current conditions.

1.3.5. Sustainable development

The objective of sustainable development activities is to improve visitors' understanding of the site and its context. At the same time, a management plan will be implemented for the maintenance of the site in a systematic manner. In addition, the natural environment of the site will be conserved and managed in order to avoid any harm to the site or its visitors.

Figure 1.3.4 Route from Ta Keo to Preah Khan (2017)

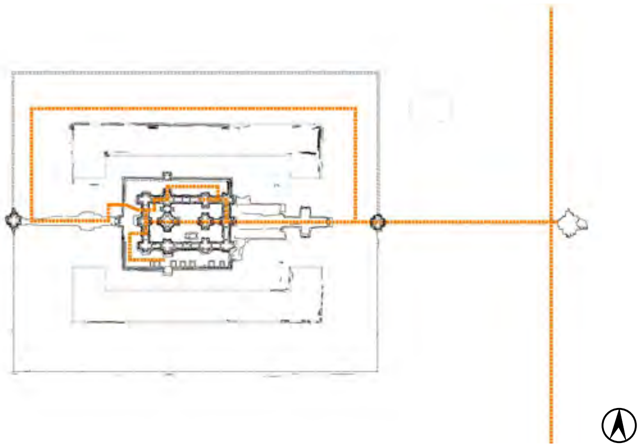


Figure 1.3.5 Visitor's route at Ta Nei

1. Presentation: visitor's routes and facilities

- Visitors are expected to arrive to the temple on foot. A walking route beginning from the east side of the Ta Keo Temple, going through a walkway on top of the West Embankment of the East Baray, and finishing at the east entrance terrace and approach of Ta Nei will be created. The route will be further extended from here to Preah Khan through the pier on the south side of the North Baray (Figure 1.3.4).
- A resting and interpretation facility will be created near the east approach way in order to improve visitors' understanding of the site. A preliminary survey will be conducted to determine any possible damage to underground remains before installing a restroom. The existing training facility and restroom will be removed.
- The visiting route will include the central axis: Terrace on West Embankment of the East Baray, East Gate, East Tower Shrine, Central Tower Shrine, and West Gate. Parts of the Inner and Outer Galleries, including the pedestals to the south, will also be opened for visitors. The return path will circle around the outside of the Moat (Figure 1.3.5). Guidance signs and explanation panels will be installed along the visiting route.
- Inside the central temple compound, the accessible areas and visiting routes will be demarcated using a rope fence or similar. Wooden walkways and stairs will be used at dangerous spots on the route.

2. Management facilities, roads, and staff

Facilities

- A resting and storage facility for the maintenance staff will be created inside the Embankment near the southwest corner. The existing working shed and guard room will be removed.

Roads

- The unpaved road leading to the west side of the temple will be retained as it is currently used to access a touristic facility (zipline) as well as the facilities by the river. However, the branch road that leads to the southwest end of the Enclosure will be restricted to only maintenance vehicles, and the route to the north side of the West Gate will be discontinued.
- A maintenance road along the north side of the Enclosure will connect to the East Gate.

Staff

- Permanent maintenance staff will continuously check and monitor the condition of the site, especially the dangerous areas, apart from taking care of visitors' safety and reporting other issues.
- Specialized staff will conduct a monthly inspection in order to monitor the condition of the site and the natural environment.

In case of sudden extreme weather conditions such as strong winds or heavy rainfall, an emergency check of the site' s condition will be carried out. If any irregularities are found, safety measures will be taken urgently in order to prevent further damage.

3. Environmental conservation and risk management

- Periodical weeding of the undergrowth around the east approach way, the east (front) side of the Enclosure, and the inside of the Enclosure will be performed; small diameter shrubs will be cleared to ensure adequate ventilation and to preserve the views.
- A drainage system will be created to drain rainwater from the waterlogged areas inside the main temple compound to the north and south Moats.
- Trees that can cause damage to the site by falling or shedding branches will be identified, monitored, and felled if necessary.

1.4. History of Cooperation between APSARA and TOBUNKEN

TOMODA Masahiko

The Institute, in the name of the Independent Administrative Institution National Research Institute for Cultural Properties, concluded its first Memorandum of Understanding (MOU) with the Authority for the Protection and Management of Angkor and the Region of Siem Reap (APSARA) in December 2001. By renewing this agreement since then, they have continued the mutual cooperative relationship for conservation of the ancient ruins. During the initial stage, they had decided to undertake a joint study on the biodeterioration of the stone monuments in Angkor, for which Ta Nei was selected as the principal site for the field investigation. The reasons for this selection were as follows: (i) it is a typical temple from the Bayon period in which such kind of deterioration is observed most significantly; (ii) it is less affected by external factors such as traffic and tourists, despite its location in the central area of the Angkor Monuments; (iii) at the time, APSARA was implementing an on-site training programme for its young staff. This joint study on the microorganisms continued until 2011, and the results were disseminated at a seminar organised at the APSARA headquarters in January 2013, and also published as a report titled 'Study on the Biodeterioration of Stone Monuments in Angkor' .

From 2012 to 2014, four separate field training programmes on architectural measuring techniques were implemented at Ta Nei. In addition to the staff of APSARA, Cambodian staff members from Preah Vihear Authority and the Japan-APSARA Safeguarding Angkor (JASA) team also participated in these programmes to learn various measuring techniques, such as the use of Total Station and photogrammetry methods. At that time, H.E. Mr. ROS Borath, then deputy director general of APSARA, had expressed his intention to implement a pilot conservation project for Ta Nei in which APSARA would take the initiative, and requested Tokyo National Research Institute for Cultural Properties (TOBUNKEN) to provide technical assistance for the project. In response to this, from 2014 onward, TOBUNKEN and the APSARA staff began preparative works such as the documentation of the current situation of the site by using SfM and other techniques. In January 2017, the "Workshop on the Conservation, Management, and Enhancement Plan for Ta Nei Temple" was held at the APSARA headquarters, where the general direction of the plan was agreed upon. After reporting the outline of this plan at the 28th technical session of the International Coordinating Committee for the Safeguarding and Development of the Historic Site of Angkor (ICC) in June 2017, the archaeological excavation survey and the investigation of the risk areas in each building were commenced in the following month.

The current MOU was renewed in March 2021 as a tripartite cooperation agreement between APSARA, TOBUNKEN, and the Nara National Research Institute for Cultural Properties (NABUNKEN). Within this framework, the archaeological excavation at Ta Nei is being performed with the advice and assistance of the NABUNKEN.

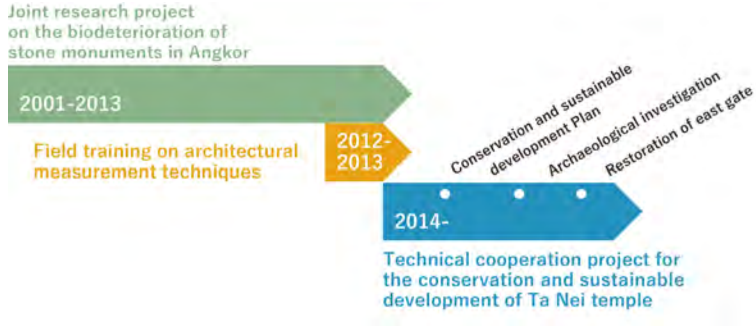


Figure 1.4.1 Cooperation history between APSARA and TOBUNKEN

Chapter 2

Outline of the Restoration of the East Gate

2.1. Purpose and Basic Policies for Restoration

TOMODA Masahiko

As mentioned in Chapter 1, the East Gate serves as the main entrance to the Ta Nei Temple. It plays a crucial role in achieving one of the objectives outlined in the archaeological site's conservation and sustainable development plan – presenting an accurate front façade of the temple while restoring its original approach, ensuring that visitors obtain a correct understanding of the temple's layout. Before restoration, the main structure of the East Gate had undergone significant deformation, and part of the roof had collapsed, narrowly avoiding complete ruin thanks to provisional supports. Consequently, the decision was made to restore the East Gate based on the following fundamental policies.

[Policy 1: Restore the building to its original form wherever possible]

As for the East Gate's superstructure, little remained of its original appearance, especially at the central part of the roof. Its original form is only conceivable based on how the West Gate looked, which was assumed to be more or less similar to the East Gate in terms of scale and form. On the other hand, except for some parts, the collapsed members of the East Gate had been left untouched; therefore, it was deemed likely that members would be found in close vicinity to where they had originally been. This is common to many of the buildings at the Ta Nei Temple site. However, in the case of the East Gate, it was expected that members of it could be identified with relative ease without the danger of mixing them up with the collapsed members of other buildings, as the East Gate stood independently of other buildings that composed the Central Complex. The aim is to accurately restore the building's original appearance, including the roof, with minimal room for imaginative input, while reusing the recovered materials to the greatest extent possible.

[Policy 2: Ensure safe passage for visitors]

Considering the current state of the site as a whole and the basic policies of the conservation and sustainable development plan, the plan identifies the temple's central axis, running from the eastern approach to the Central Complex, as the primary passage for visitors. The inside of the East Gate was the only section of this central axis that was blocked and made impassable by the accumulated rubble and sediment. It is necessary for the restoration of the East Gate to restore the building's appearance and ensure a safe and unhindered passage

Figure 2.1.1 East Gate before restoration in 2004

Figure 2.1.2 West Gate (from the southwest)

for visitors through the inside of the building from the east to the west entrance. This makes it especially important to rebuild the central part of the collapsed roof stably.

[Policy 3: Ensure structural integrity and reduce the risk of repeated deformations in the future]

The nature of the East Gate's damage and deformation before the restoration, as well as the mechanisms leading up to that, will be described later. Even with the elimination of external factors such as vegetation growth, the structural vulnerability inherent in the building will remain. Even if the deformation is fixed, and the building is restored to its original soundness, it is destined to become deformed again in the long term, causing a loss of structural balance and ultimately a renewed collapse of the roof. Following the analysis of the building's structural vulnerability, the restoration work will involve the application of appropriate reinforcement and stability-boosting measures according to scientific considerations. Such interventions are necessary to ensure visitor safety, which also falls under the second objective.

[Policy 4: Ensure authenticity as it is a crucial element of a World Heritage Site]

The Ta Nei Temple site is an asset that is part of the World Heritage Site 'Angkor', with the East Gate being an essential component. A crucial premise for undertaking this restoration work is compliance with the requirements outlined in the 'Operational Guidelines for the Implementation of the World Heritage Convention', which includes the 'Venice Charter' and the 'Nara Document on Authenticity'. These are international standards governing the conservation and restoration of architectural heritage and the preservation of authenticity. Authenticity must be maintained in terms of the four basic requirements: 'design', 'material', 'technique', and 'settings'. Additionally, restoration efforts should align with the principles established in the 'Angkor Charter'.

Figure 2.1.3 Collapsed members of the East Gate found during the excavation

Figure 2.1.4 Inside the East Gate before restoration

2.2. Project Members

APSARA

KIM Sothin: Deputy Director General, APSARA

SOM Sopharath: Director, Department of Conservation of Monuments and Preventive Archaeology (DCMA)

IM Sokrithy: Director, Department of Research Training and Communication

EA Darith: Director, Department of Conservation and Archaeology at the National Authority for Preah Vihear

TANN Sophal: Deputy Director, DCMA

SEA Sophearun: Researcher (Archaeology), DCMA

SITHA Visaraboth: Researcher (Archaeology), DCMA

DOY Pichjira: Researcher (Engineering), DCMA

PROM Titchhopnnarith: Researcher (Architecture), DCMA

THAI Yamang: Researcher (Architecture), DCMA

RO Sovandaroath: Conservator, DCMA

MOM Sophon: Conservator, DCMA

PRUM Sopheak: Conservator, DCMA

CHHAY Loeun: Conservator, DCMA

KEO Diamant: Trainee (Archaeology), DCMA

NHOK Lo: Consultant, DCMA

THON Neam: Consultant, DCMA

Figure 2.2.1 APSARA on-site staff

TOBUNKEN

TOMODA Masahiko: Deputy Director General (Architecture), TOBUNKEN (2011-2023 missions)

KANAI Ken: Head (Architecture), Resource and Systems Research Section, Japan Centre for International Cooperation in Conservation (JCICC), TOBUNKEN (2019-2022 missions)

ABE Masashi: Head (Archaeology), Conservation Design Section, JCICC, TOBUNKEN (2017-2019 missions)

MARTINEZ Alejandro: Former Associate Fellow, JCICC, TOBUNKEN (2017-2019 missions), Assistant Professor (Architecture), Kyoto Institute of Technology

KANSHA Hiroo: Former Associate Fellow (Archaeology), JCICC, TOBUNKEN (2017-2022 missions)

ASADA Natsumi: Researcher (Architecture), JCICC, TOBUNKEN (2019-2023 missions)

VAR Elif Berna: Former Associate Fellow (Architecture), JCICC, TOBUNKEN (2019-2020 missions)

YAMADA Ayano: Associate Fellow (Archaeology), JCICC, TOBUNKEN (2022-2023 missions)

KUROIWA Chihiro: Associate Fellow (Architecture), JCICC, TOBUNKEN (2023 mission)

INUZUKA Masahide: Deputy Director (Phisical Measure), Centre for Conservation Science, TOBUNKEN

NISHIDA Noriyoshi: Associate Fellow (Analytical Science), Centre for Conservation Science, TOBUNKEN

Japanese external experts

KOSHIHARA Mikio: Professor (Structural Engineering), the University of Tokyo (2016 mission)
OISHI Takeshi: Associate Professor (Spatiotemporal Media Engineering), the University of Tokyo (2019, 2020 missions)
KUWANO Reiko: Professor (Geotechnical Engineering), the University of Tokyo (2019 mission)
OTSUBO Masahide: Assistant Professor (Geotechnical Engineering), the University of Tokyo (2019 mission)
KUBO Makiko: Lecturer, Faculty of Buddhist Studies, Rissho University

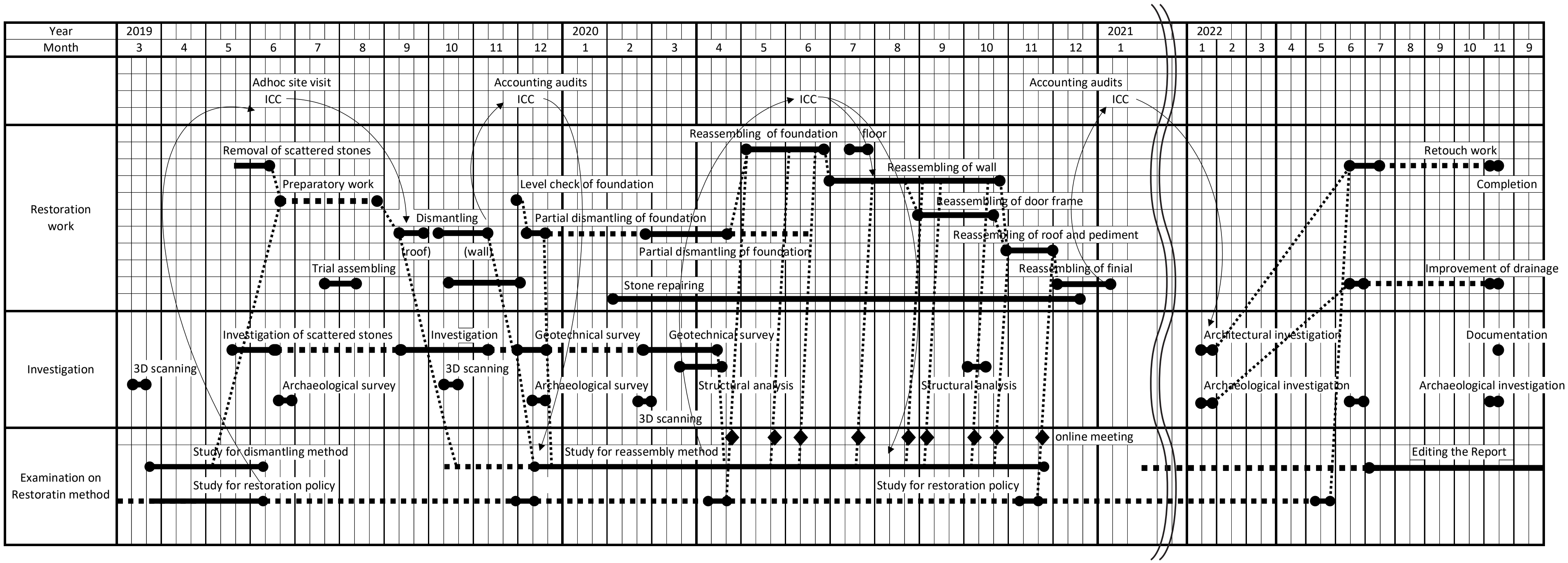
2.3. Project Budget

The budget for construction work of the East Gate restoration (126,707 USD) was covered by APSARA, while the budget for investigation and technical support was covered by TOBUNKEN.

2.4. Project Schedule

Restoration work of the East Gate began in the middle of 2019 after the 32nd Technical Session of the International Coordinating Committee for Safeguarding and Development of the Historic Site of Angkor (ICC-Angkor) adopted the restoration plan in June. Dismantlement of the upper structure was completed in November 2019. Subsequently, the base structure was partially dismantled for archaeological and geotechnical research in December 2020. Because of worldwide travel bans against the COVID-19 pandemic, onsite cooperation between APSARA and TOBUNKEN was suddenly suspended. APSARA carried out the restoration work as planned, while TOBUNKEN provided support using information and communication technology (ICT), including active online discussions. Following the recommendation of Ad-hoc experts, restoration methods were decided during the online meeting between two parties, and reassembly work was completed in December 2021. In 2022, after the lift of travel restriction, onsite cooperation between APSARA and TOBUNKEN was resumed. Supplemental retouch work of the East Gate was conducted in June and November 2022, and the East Gate restoration was finally completed. (Table 2.5.1)

Table 2.4.1 Project schedule of the restoration work



Chapter 3

Outline of the Building

3.1. Outline of the East Gate

KANAI Ken

The East Gate, the original main entrance of the temple, is relatively small and simple compared to the main gates of other Angkor temples. The building, made of sandstone, has a regular cruciform plan with entrance openings to the east and west sides and has a length of 6 m on each side. Laterite walls of the Outermost Enclosure were originally attached to the north and south sides of the gates, but these walls have been lost, leaving only a part of the basement.

The roof structure is a cross-vault constructed using corbeling, and wooden ceiling was assumed to be stretched above the cornice. The dome-like roof decoration with tiered finial is placed on the top centre of the roof (Figure 3.1.1).

The exterior has rich decoration with carving, a Devata figure on the outer edge, a false window on the centre of each internal corner wall, and Buddhist mythological scenes on the pediments of four protruding surfaces. The carving theme on the front pediment is "Avalokitesvara (Buddhist God of Mercy) giving amrta (nectar of the gods) to pretas (hungry ghosts)," which is rarely seen in other Angkor temples (see Chapter 10). This unique motif may explain the reason of founding the temple.

The East Gate of the Ta Nei Temple is small in scale, simple in structure, and not very eye-catching. However, the building is largely unmodified, remains well preserved not only in its structure but also in its components, and is precious for directly bringing ancient architectural techniques to our times.

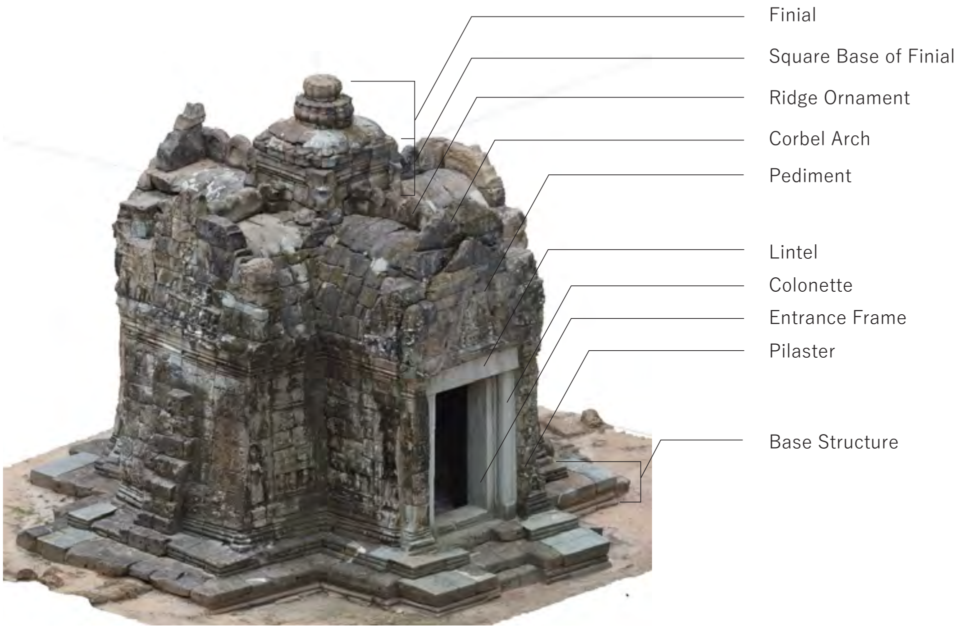


Figure 3.1.1 Architectural composition of the East Gate

3.2. Comparative Study on Architectural Features of the Outermost Gate

KUROIWA Chihiro

3.2.1. Introduction

The architecture of the East Gate of Ta Nei Temple, as mentioned in the previous section, is unique in terms of scale, plan, roof structure, and other features unexceptional among the gate architecture of other temples. For this reason, the characteristics, construction period, and significance of the East Gate have not been placed in the context of other temple architectures of the same period. Through this restoration work, after reassembling the scattered stones, the entire view of the East Gate building can finally be seen in its present situation. As a result, it is now possible to analyse its architectural features.

In this section, we discuss the architectural characteristics of the East Gate of Ta Nei Temple in reference to previous research, results of a field survey of the gate buildings of other temples constructed during the same period, and comparison of the architectural components with similar examples, to appropriately place those characteristics in the Khmer architectural history.

3.2.2. Details of Architectural Characteristics of the East Gate, Ta Nei Temple

(1) Architectural Planning of the East Gate

Where does the architectural uniqueness of the East Gate of Ta Nei Temple originate? Before discussing comparisons with other temple architectures of the same period, the following summary of the characteristics of the East Gate is presented from several viewpoints of architecture elements.

First of all, it is necessary to consider the plan configuration. The East Gate was constructed with a cross-shaped plan for which it was found that the east-west and north-south axes are not symmetrical, although distortions caused by low construction accuracy should be taken into consideration when considering reasons for the asymmetry.

Figure 3.2.1 shows the construction features of which the main dimensions were obtained by tape measurements. The actual dimensions of the interior walls show that the width and depth of the south part of the cross-shaped plan are approximately 200 mm larger than those on the north part, and the floor area is larger (Figures 3.2.2-3.2.3). If taken as a dimensional difference due to construction accuracy, it is relatively large for a single building of 6-m scale. The east and west parts have generally similar dimensional values. In addition, it can be seen from visual inspection and the photogrammetric model that the east wall of the south part is not particularly perpendicular to the connecting walls and is clearly inclined (Figure 3.2.1).

The dimensional plan of the exterior walls shows less difference than that of the interior walls, with the north exterior walls on both east and west sides being about 100 mm smaller than the south exterior walls. This points to the possibility that the building was planned in an asymmetrical configuration in the north-south direction.

In addition, the intersection of the cross-shaped walls does not have external corners as seen in many other temple gate buildings, and similarly, the base does not have an external corner either, resulting in a simple cross-shaped plan (Figure 3.2.4). The presence or absence of an external corner is assumed to be related to the upper structure it supports. The roof structure is described in detail in the following subsection 3.2.2 (3).

The sandstone base structure is not uniform in width, having several stones that are not clearly shaped. Thus, the dimensional planning of the sandstone base is unclear. The sandstone base consists of two layers, an upper and a lower. The initial ground level around the East Gate varies in height from east to west, with the east side being lower than west side. Thus, in the northwest part of the upper layer of the base, there was a point where the heights of the upper and lower layers of the base did not match, and there are traces of adjustment where the upper layer was gradually curved down to match the surface of the lower layer to absorb the difference in height (Figure 3.2.5).

As a comparison, differences with the West Gate of the Outermost Enclosure were confirmed (Figures 3.2.6-3.2.7). There is no significant difference in the plan scale between the West and East Gates (Figure 3.2.8). However, it should be noted that, unlike the East Gate, the West Gate does not differ significantly in the width or depth of the convexity between the south and north sides, with only the east part of the south side being about 300 mm smaller than the other sides. On the exterior walls, the north side of the wall on the east face and the south side of the wall on the west face are 300-400 mm larger than the opposite sides, creating a distorted effect as if the entire building were twisted, rather than a north-south shift of the building's central axis.

The structure of the West Gate is similar to that of the East Gate in that it does not have an external corner at the intersection of the cross-shaped walls and has a two-layered sandstone base. At the West Gate, there is also a height difference between the east and west sides of the construction site, with the west side lower, so it appears as though it had been adjusted at the base, but some of the details have not been confirmed because it is partially buried under collapsed stones and other debris.

Figure 3.2.1 Photogrammetry plan and main dimensions by hand measurement of the East Gate (the north on top)

Figure 3.2.2 (top) South interior view
Figure 3.2.3 (bottom) North interior view

Figure 3.2.4 Internal corner of the East Gate

Figure 3.2.5 Traces of adjustment of the difference in height at the base

Figure 3.2.6 East view of the West Gate

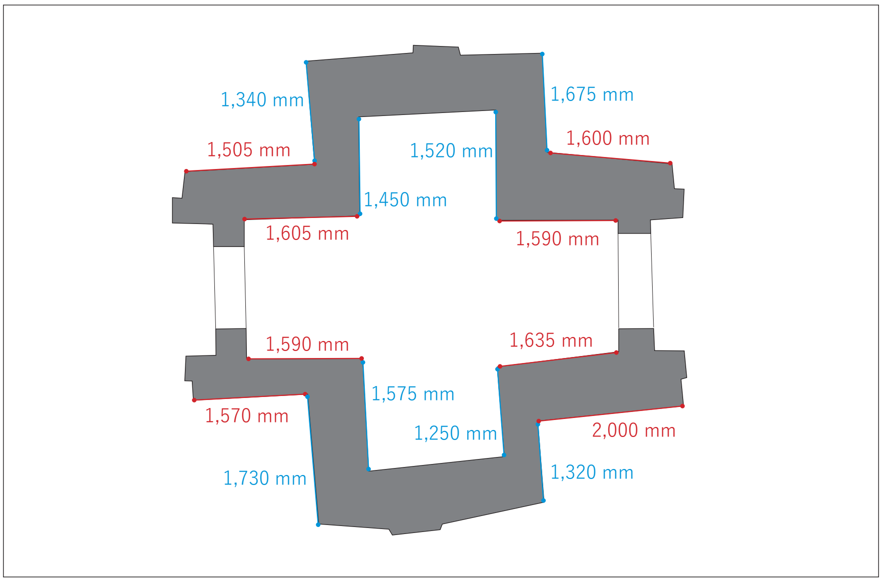


Figure 3.2.7 Schematic drawing and the main dimensions by hand measurement of the Wes Gate (the north on top)

(2) Planning of the temple complex and the East Gate

Next, the layout planning within the complex was analysed.

When viewing the Inner Gallery from the East Gate, it can be seen that the entrance ways of the two structures are slightly misaligned. Based on measured drawings that have been produced since 2012, as seen on Figure 3.2.8, lines drawn through the centre points of the East Gate and West Gate (shown in green) in parallel with the axis of the Central Complex (in red; a line passing through the east-west entrance of the Inner Gallery and Central Tower Shrine), reveal that the centre line of the East Gate is shifted to the south by approximately 567 mm compared to the axis line of the Central Complex, and that the centre line of the West Gate is shifted approximately 590 mm to the north compared to the axis of the Central Complex. However, it is possible that the axes of the East and West Gates themselves are inclined compared to the axis of the Inner Gallery, as has been mentioned in the report of the previous measurement survey (Sato & Park, 2014).

Also, other previous research suggested that there were additions and alterations from the initial construction within the Inner Gallery at Ta Nei Temple, and that the Outer Gallery and the East and West Gates on the Outermost Enclosure were added later than the Inner Gallery (Cunin, 2004). To understand the reasons for the misalignment of the East and West Gates and Inner Gallery, it will be necessary to clarify the layout planning based on a more detailed measurement survey of the entire temple complex, while taking into consideration the differences in construction period and accuracy, and to consider the transition process, including modifications of planning due to additions and alterations.

To that effect, a survey was carried out to investigate how the axial misalignment was manipulated in the temple complex. The results confirmed that there is a difference in the length of the north and south wings on the eastern side of the Inner Gallery. Also, it was discovered that there were differences between the north and south wings in the composition of the decorations of the false windows and Devata images.

The south wing has two false windows on the south side of the entrance (Figure 3.2.10) and two false windows with one Devata image between them on the north side of the entrance (Figure 3.2.11). The north wing, on the other hand, has one false window and two Devata images on the south side of the entrance (Figure 3.2.12), and one false window and one Devata image on the north side of the entrance (Figure 3.2.13).

The differences in the dimensions of the north and south wings due to these different components was confirmed by tape measurements: the south wing is 2,974 mm to the south of the entrance and 3,250 mm to the north of the entrance; the north wing is 2,622 mm to the south of the entrance and 2,413 mm to the north of the entrance. The south wing is 1,189 mm longer in total than the north wing, which causes the axis of the Inner Gallery to be oriented to the north against the central line of the entire length of the east side of the Inner Gallery.

Reports of previous studies of Khmer temples have shown that the central shrine and other buildings are not placed on a central line dividing the entire north-south axis of the temple complex equally, but that the temple axis is almost exclusively shifted slightly to the north in the temples facing the east (Mizoguchi & et al., 2007). It is thus necessary to further examine how the outermost gate was positioned and added in the layout planning of Ta Nei Temple.

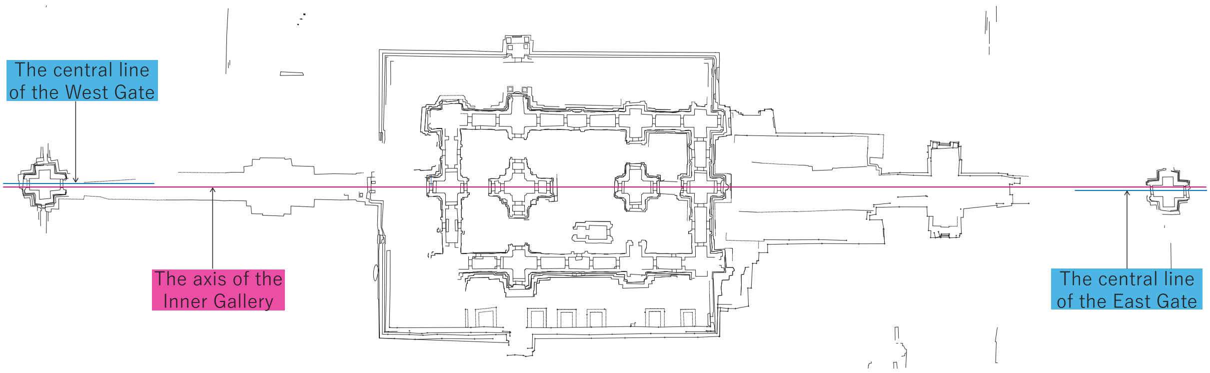


Figure 3.2.8 Misalignment of the axes between Inner Gallery and West Gate/East Gate

Figure 3.2.9 Entire view of the east side of the Inner Gallery

Figure 3.2.10 South side of south wing

Figure 3.2.11 North side of south wing

Figure 3.2.12 South side of north wing

Figure 3.2.13 North side of north wing

(3) Roof structure and decoration

One of the elements that distinguishes the uniqueness of the East Gate is the roof structure. The dome-like roof over the cross vault of the corbel arch seen in this structure is rarely found in Khmer architecture (Figure 3.2.14).

The structure consists of a relatively horizontal top surface at the intersection of the cross vaults and a square base of a finial with carved side walls, topped by a dome-like roof with rounded lotus-like carved edges and two tiers of a lotus-shaped pedestals at the top.

The head of the second tier is also horizontal, and it is possible that another element of the finial had existed on the top, as will be described in Section 5.2. Furthermore, when a tower-like structure is included at the top, an external corner is often added to each internal corner of the wall section, and a cornice with the external corners is placed above the wall to support the tower-like structure. The East Gate, however, is not in this architectural style, and the top structure is placed on the vault without external corners.

The four corners of the dome-like roof are decorated with carvings of Garuda, which seem to be continuous from the internal corners where the vaulted roof intersects. On the southeast and southwest corners, the lower part of the Garuda is missing and details are not available, but several small triangular protrusions can be seen under the Garuda on the northeast and northwest corners (Figures 3.2.15-3.2.16).

The edges of each protrusion also show circular or wavy carvings that look like the head of a Naga. There is a possibility that this is a motif of a Garuda straddling one of the Naga's multiple heads, as is often seen on the ends of balustrades in structures of the Bayon period, but it is remarkable here that the proportion of the Naga's head is comparatively smaller than that of the carving of Garuda on the Naga seen on those balustrades. Previous studies have shown that the importance of Garuda motif increased rapidly in the late Bayon period, and the motif of a Garuda straddling a multi-headed Naga has been considered as a transition in the image of the Garuda in Buddhist iconography (Boisselier, 1951; Sharrock, 2009).

Figure 3.2.14 Roof structure of the East Gate

Figure 3.2.15 Garuda of north-west corner modeled by photogrammetry

Figure 3.2.16 Garuda of north-east corner modeled by photogrammetry

(4) Access to the East Gate and other features

At the East Gate, there are no openings except for the east-west entrances. There are also many as yet not well-understood points, such as the placement of the head of Lokeshvara inside the East Gate, discovered during the clearance work at dismantlement (refer to Section 4.2), and an egg-shaped niche-like cavity in the south wall of the west part of interior wall (refer to Section 4.3/Figure 4.3.24), which was also described in the journal of H. Marchal in 1929 (Marchal & Fombertaux, 1928-1930). From the trace survey, the spatial characteristics of the East Gate were confirmed.

Based on the results, traces presumed to be those of wooden members that support the wooden door panels were identified on the inner side of the east door frame at the East Gate (Figures 3.2.17-3.2.18). At the West Gate, similar traces were found only on the inner side of the west door frame (Figure 3.2.19). Although it is unclear whether the traces were added at the time of construction or at a later period, the fact that they are found only on the outer side of the building suggests the possibility that the gate was planned as an accessway rather than as a sacred religious space, and that every door could be closed, creating a place for a statue of a deity in the centre.

The differences and similarities between the East and West Gates based on the trace survey can be briefly summarised as follows: For the West Gate, a single piece of stone was used to create the intersection of the walls (Figure 3.2.21), while for the East Gate, two pieces of stone were sometimes used (Figure 3.2.20). The stonework and construction method of the West Gate were more carefully executed than those of the East Gate. The wall decorations consist of a single Devata and a false window with curtains on every side of both East and West Gates (Figure 3.2.22).

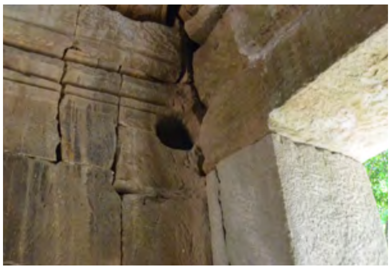


Figure 3.2.17 / Figure 3.2.18 Traces of the wooden members of the east entrance, East Gate

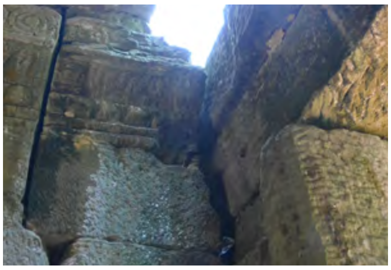


Figure 3.2.19 A trace of a wooden member of the west entrance, West Gate

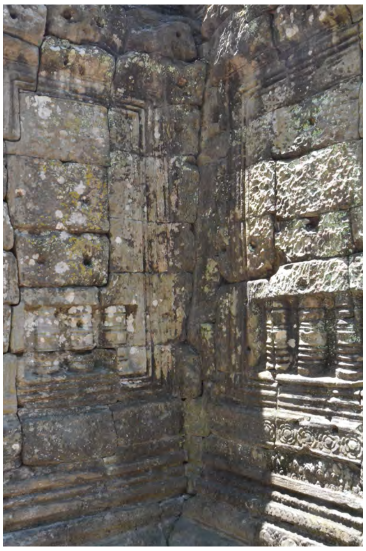


Figure 3.2.20 Wall intersection, East Gate

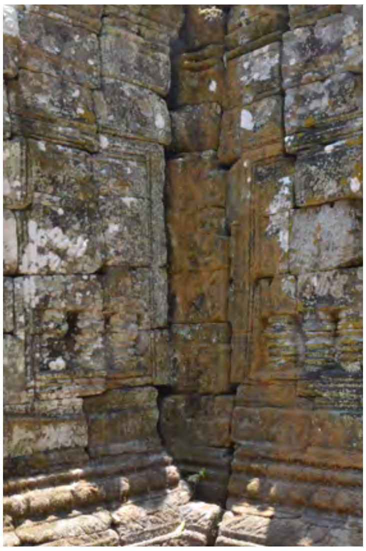


Figure 3.2.21 Wall intersection, West Gate


Figure 3.2.22 A false window and a Devata curved on the wall, East Gate

3.2.3. Comparative survey with the East Gate

(1) Purpose and the previous study

In the previous sections, architectural features of the East Gate of Ta Nei Temple and its role as the outermost gate of the temple were examined.

To clarify the characteristics of the East Gate, this section focuses on comparison with other temple buildings of the same period. In selecting buildings of the same period for comparison, "De Ta Prohm au Bayon" (Cunin, 2004) was referred to, which provides chronological consideration of each building based on analysis of the process of modification and expansion in the temple complex and examination of the decoration and other elements of temples classified as part of the Bayon period. In his study, the Bayon style was subdivided into the Ta Prohm period, the Preah Khan I and II periods, and the Bayon I and II periods.

The construction of East and West Gates of the Outermost Enclosure of Ta Nei Temple is placed approximately at the same time with that of the Outer Gallery, and is considered to be of the Bayon II period, which was the latest phase of Bayon style, although the construction order among the buildings is not known. It is also believed that only the Devata image of Ta Nei Temple slightly precedes the Bayon temple. On the other hand, it is highly possible that most of the Bayon period decorations are exceptionally late and unrelated to the construction period, and it is considered that the Devata image does not substantially differ in age from the Bayon II period.

For this reason, this comparative study focuses on temple buildings that were constructed in the Bayon II period. In many cases, the temples originally built in the Bayon periods have been extended and altered multiple times: those and other buildings among the Angkor Monuments that are considered as Bayon II period in that study are listed as below.

- Ta Prohm Temple: Addition of the Second Enclosure
- Preah Khan (Angkor) Temple: Addition of the Second Enclosure
- Banteay Kdei Temple: Addition of the Second Enclosure
- Bayon Temple: Outer Gallery and Libraries
- Banteay Chhmar Temple: Addition of the 3rd Enclosure, First and Second Satellite Temples
- Vat Nokor Temple: Addition of the Third Enclosure

In addition, there are temples that are presumed to have been constructed during the Bayon I period, and for which the decoration and other features are positioned in the Bayon II period. The following are those temples only within the Angkor Monuments:

- Banteay Prei Temple/ - Ta Som Temple/ - Krol Ko Temple/ - Neak Pean

In the present study, a complete visual survey was conducted during the field work as a pre-survey. To clarify the special features of Ta Nei Temple, further architectural measurement surveys will be necessary for the future.

(2) Survey method and target temples

For comparison with the East Gate of Ta Nei Temple, from among the above-mentioned temple complexes having several layers of enclosures which are located among the Angkor Monuments, six temples were selected as subjects of comparison. The following is an outline of the survey:

- Survey Period: May 6 to 17, 2023
- Survey Target Temples: Ta Prohm, Preah Khan, Banteay Kdei, Ta Som, Banteay Prei, Banteay Thom;

total 6 temples

- Survey Methods: Confirmation of the composition of the temple complex, analysis of the architectural features of the outermost gate, decoration and wooden door trace survey, and drone photography of the roof structure (Preah Khan Temple)

A visual survey of the outermost gates was carried out to investigate the shapes, components, and traces of wooden door structures. The outermost gates showed a variety of architectural configurations, such as several having a tower with faces. A summary of the similarities and differences in the architectural overview and comparison with the Ta Nei Temple are presented below.

(3) Architectural overview of the outermost gates

This section describes the composition of the outermost gate architectures in the six target temples.

- Ta Prohm Temple:

The outermost enclosure has gates with face towers on the north, south, east, and west sides. The West Gate was observed because the East Gate was undergoing restoration. It has a cross-shaped plan, but there is no base structure in the middle area and it is a passageway through the building as the temple causeway. It consists of a chamber with a staircase and two side chambers on both north and south sides of the causeway, which are on the base structure. On the walls on both sides of the causeway, there are two attached columns each on both east and west sides of a staircase.

The upper structure is the cross vault roof of the corbel arch, on which the tower rises. Each external corner of the outer wall has a sculpture of a giant Garuda straddling a multi-headed Naga, which has partially collapsed. Further above, a Naga sculpture is placed at the external corner above the corbel arch, supporting the bottom part of the tower. The tower is carved with faces of the deity on four sides. (Figures 3.2.23-3.2.25)

- Preah Khan Temple:

The outermost enclosure consists of gates with three towers on the north, south, east, and west sides. Each gate includes three gate; the central gate and both side gates. The tower of the central gate is larger in size and height, while the two towers of both sides are slightly smaller. The central gate has a cross-shaped plan, similar to the gate buildings of Ta Prohm Temple, and also similarly there is no base structure in the middle area and it is a passageway through the building as the temple causeway. It consists of a chamber with a staircase on both north and south sides of the causeway, which are on the base structure. On the walls on both sides of the causeway, there are two attached columns each on both sides of a staircase. Each chamber with a staircase is connected to side chambers, which in turn are connected to the both side gates. The both side gates also have cross-shaped plans, but unlike the central gate, they are situated on a base structure. There is a pedestal inside each gate, on which a statue of a deity is thought to have originally existed. There is a small rectangular side chamber on each outer side of the both side gates, where pedestals were also found.

The central gate has a tower on the cross vault of the corbel arch. The both side gates also have short cross vaults of corbel arches. At the intersections of the cross-shaped plan of the central gate, there are external corners to the wall and cornice, on which the vaulted roof rises, with the lower corners of the towers supported by the wall above it. The finial of the tower consists a lotus-shaped carving and a cylindrical curving at the top. (Figures 3.2.26-3.2.30)

- Banteay Kdei Temple:

The outermost enclosure has gates with towers on the north, south, east, and west sides. Carved faces have been identified at the East and North Gates. The West Gate is undergoing restoration, so the East Gate was observed. It has a cross-shaped plan, but there is no base structure in the middle area and it is a passageway through the building as the temple causeway. It consists of a chamber with a staircase and two side chambers on both north and south sides of the causeway, which are on the base structure. On the walls on both sides of the causeway, there are two attached columns on both east and west sides of a staircase.

The upper structure is the cross vault of the corbel arch, on which the tower rises. Each external corner of the outer wall has a sculpture of a giant Garuda straddling a multi-headed Naga, which functions as the external corner. A Naga carving above the Garuda supports the bottom of the tower. The East Gate tower still retains faces of the deity on four sides. The West Gate has collapsed. It is similar in plan and components to the outermost gate of Ta Prohm. (Figures 3.2.31-3.2.32)

- Ta Som Temple:

The outermost enclosure has gates with face towers on the north, south, east, and west sides. The faces have been placed chronologically in the previous study (Cunin, 2004) at the same time as the faces of Banteay Kdei and Ta Prohm Temples. It has a cross-shaped plan, with a causeway passing through in the middle area. On the walls on both sides of the causeway, there are two attached columns each on the east and west sides of the entrance to the side chambers.

The cross-shaped plan is covered by the cross vault of the corbel arch, on which the tower rises. It is noteworthy that the corner of the outer wall has external corners, but it has collapsed in the middle and the upper structure is not directly related to the tower. (Figures 3.2.33 - 3.2.34)

- Banteay Prei Temple:

Only a small and simple sandstone gate or door frame was set into the outermost enclosure of the laterite, which has collapsed, with some elements of the door frame remaining. (Figure 3.2.35)

- Banteay Thom Temple:

The outermost enclosure has a gate on the east side only, with a cross-shaped terrace in front of it. The East Gate has a main chamber with a cross-shaped plan, porches with pillars on both east and west sides, and side chambers extending to both north and south sides. The central main chamber with a cross-shaped plan has entrances on the north, south, east, and west sides.

The roof has partially collapsed in the middle, but it can be seen that the central main chamber has a cross vault of the corbel arch, and the side chambers were also constructed from the corbel arch. (Figure 3.2.36)

The above observations show that large temples such as Ta Prohm, Preah Khan, and Banteay Kdei have towers built on top of the corbel arch, and the corners of the towers are also characteristic of this style. The fact that the external corner does not directly support the tower but rises on the corbel arch in Ta Som Temple is similar to the structure of the roof over the corbel arch of the outermost gate of Ta Nei Temple.

(4) Planning of temple complexs and the outermost gates

Although it was difficult to visually confirm in the larger temples, in the medium-sized Banteay Prei and Banteay Thom Temples, it was visually confirmed that there was a misalignment in the axes between the outermost gate and its inner enclosure. For example, in Banteay Thom Temple, the number of rows of masonry is different between the north and south sides of the Inner Enclosure, which points to the possibility the misalignment of the axis with the central line of the temple complex was planned. Further measurement surveys are required to confirm the planning method.

(5) Roof structures and decorations

In Subsection (3), an outline of the corbel arch and tower structure was described for six temples for

Figure 3.2.23 East view of the West Gate, Ta Prohm Temple

Figure 3.2.24 Wall intersection with Garuda curving

Figure 3.2.25 Naga and the bottom of the tower

Figure 3.2.26 East view of the West Gate, Preah Khan Temple

Figure 3.2.27 Chamber with a staircase, East Gate

Figure 3.2.28 Pedestal in the North Gate of the East Gate

Figure 3.2.29 The Central Gate of the East Gate, Preah Khan Temple

Figure 3.2.30 The South Gate of the East Gate

Figure 3.2.31 East Gate, Banteay Kdei Temple

Figure 3.2.32 Garuda as an external corner of the wall

Figure 3.2.33 West Gate, Ta Som Temple

Figure 3.2.34 The external corner of the wall

Figure 3.2.35 Remaining of the gate, Banteay Prei Temple

Figure 3.2.36 East Gate, Banteay Thom Temple

comparison with Ta Nei Temple, but the architecture of the outermost gate of the other temples does not have a dome-like roof like that of the outermost gate of Ta Nei Temple. Thus, a comparative study of the shape and decoration of the roof of Ta Nei Temple against those of other buildings of the same period was conducted.

First, dome-like roofs can be seen on the eight sub-shrines in the western area of the Central Gallery of Preah Khan Temple. Each building consists of a rectangular main chamber and a porch on its west side. In the roof structure, the walls rise vertically inside the pediment of the main chamber, which is covered by a thick dome-like roof with about five layers of stone masonry. At the top is another layer of a similarly dome-like small roof with a cylindrical finial. The overall proportions of the roof are different from those of Ta Nei Temple, which is built on the vault roof with thick vertical base walls and thin dome-like masonry. The masonry methods used in the construction of the two temples are very different. In addition, the Garuda decorations on the four corners and the lotus curving of the finial of Ta Nei are not implemented in Preah Khan Temple. (Figures 3.2.37-3.2.39)

Examples of the Garuda decoration straddling the small triangular protrusion identified at the outermost gates of Ta Nei Temple were also observed at the following positions in several other temples:

- Preah Khan:

The corner edge of the cornice on a row of pillars inside the Second Enclosure (Figure 3.2.40)

- Banteay Kdei:

The corner edge of the cornice on a row of pillars inside the Second Enclosure (Figure 3.2.41)

- Ta Prohm:

The corner edge of the cornice on the pillars inside the Hall of Dancers (Figures 3.2.42-3.2.43)

At Ta Prohm Temple, a decoration of Garuda can be seen at the cornice on a row of pillars inside the Second Enclosure, similarly with the two temples above, although it is unclear whether there was a small triangular protrusion at the bottom of Garuda due to the poor condition of the remaining structure (Figure 3.2.44). These are carved in the corners, and according to Roveda, 2005, "It is difficult to define the real nature of this bird," but it is reported as a motif that often appears in the corners of architectural components, such as the corner of the column heads at East Mebon.

Cunin's discussion suggests that the extension of the Second Enclosures of the above three temples is placed in the Bayon II period, similarly with the East Gate of Ta Nei Temple, and that the Garuda decoration straddling the small triangular protrusion might be a feature of the sculpture of the late period (Cunin, 2004).

(6) Access to the outermost gates

Based on the survey of the outermost gates, traces of wooden door structures were found at the following temples:

- Ta Prohm Temple:

Traces of a wooden door frame were discovered on the surface around the attached columns of the outer entrance on the walls of both sides of the causeway. No traces were found around the attached columns of the inner entrance. The side chambers have not been investigated. (Figures 3.2.45-3.2.46)

- Preah Khan Temple:

Traces of a wooden door frame were discovered on the surface around the attached columns of the outer entrance on the walls of both sides of the causeway. No traces were found around the attached columns of the inner entrance. No traces of a door were found in the first side chambers, but traces of a door were found in three directions in the second side chambers where a pedestal for a religious image was found. A pedestal was also found in the outermost third side chamber, but no door traces were found at the entrance to the second side chamber. (Figures 3.2.47-3.2.48)

Figure 3.2.37 Sub-shrines at the west half part of the Inner Gallery, Preah Khan Temple

Figure 3.2.38 Sub-shrines, Preah Khan Temple

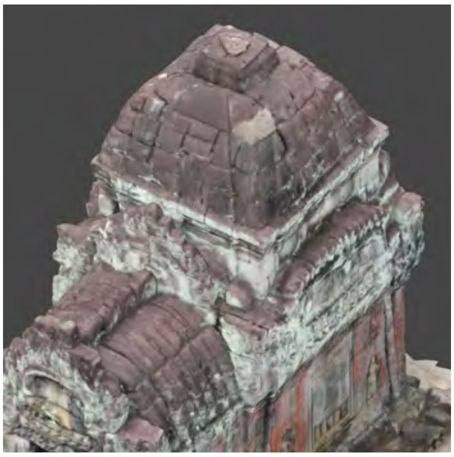


Figure 3.2.39 Roof structure of the Sub-shrine

Figure 3.2.40 Garuda, Preah Khan Temple

Figure 3.2.41 Garuda, Banteay Kdei Temple

Figure 3.2.42 Pillars of the Hall of Dancers, Ta Prohm Temple

Figure 3.2.43 Garuda in the Hall of Dancers

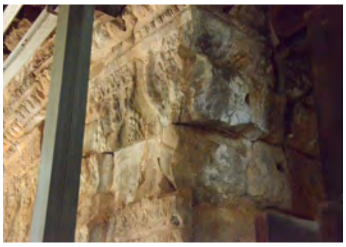


Figure 3.2.44 Garuda, inside the Second Enclosure

- Banteay Kdei Temple:

Traces of a wooden door frame were discovered on the surface around the attached columns of the outer entrance on the walls of both sides of the causeway. No traces were found around the attached columns of the inner entrance. Traces of a door were found at the entrance to the second side chamber. (Figures 3.2.49-3.2.50)

- Ta Som Temple:

Traces of a wooden door frame were discovered on the surface around the attached columns of the outer entrance on the walls of both sides of the causeway. No traces were found around the attached columns of the inner entrance. The side chambers have not been investigated. (Figure 3.2.51)

- Banteay Prei Temple:

The presence or absence of doors is unclear for the outermost simple sandstone gate (Third Enclosure) and its inner gate (Second Enclosure).

- Banteay Thom Temple:

Traces of wooden door frames can be seen on both sides of the east and west entrance of the main chamber with cross-shaped plan. (Figure 3.2.52)

From the above, it can be considered that many of the gates had doors placed only on the outer side, similarly as the East and West Gates of the Outermost Enclosure of Ta Nei Temple, and that they functioned as passageways. In addition, especially in the outermost gates of the large-scale temples, where several side chambers were attached, there is a space where the doors could be completely closed. The fact that some temples have remaining pedestals suggests that the side chambers were used for the worship of a deity image.

3.2.4. Conclusion

A tentative comparative study of the outermost gate of Ta Nei Temple and other temples of the same period confirmed their common architectural characteristics and functions. In addition, when the decoration, as one of the architectural components, was compared with that of other temples, it was reconfirmed similarly as in the previous study that the construction could be positioned as a particularly later period of the style of Bayon.

On the other hand, while the architectural style of the outermost gates of large-scale temples was becoming more formalised, the features of the outermost gate of Ta Nei Temple is unique, especially in the roof structure, and it is necessary to confirm the form, construction techniques, and decoration more extensively to understand the origin of the outermost gate of Ta Nei Temple within the context of Khmer architectural history.

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Figure 3.2.45 Traces of the wooden members at the causeway, Ta Prohm Temple

Figure 3.2.46 Traces of the wooden members at the causeway, Ta Prohm Temple

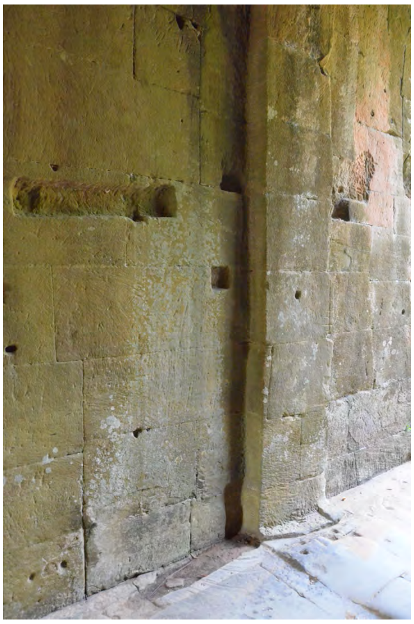

Figure 3.2.47 Traces of the wooden members at the causeway, Preah Khan Temple

Figure 3.2.48 A trace at the entrance of the side chamber, Preah Khan Temple

Figure 3.2.49 A trace at the entrance of the side chamber, Banteay Kdei Temple

Figure 3.2.50 Traces of the wooden members at the causeway, Banteay Kdei Temple

Figure 3.2.51 A trace of a wooden mmember at the causeway, Ta Som Temple

Figure 3.2.52 Traces of the wooden members at the west entrance, Banteay Thom Temple

Chapter 4

Dismantlement

4.1. Pre-Dismantlement Investigation

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4.1.1. Documentation before dismantlement

A documentation work was performed in three forms before gate dismantlement, namely, 3D laser scanning, photogrammetric documentation using Structure from Motion (SfM) and architectural documentation by manual measurement to produce drawings. SfM photogrammetry allowed to record the existing condition of the structure from all directions before starting the restoration work (Figure 4.1.1). A 3D laser scanning survey was conducted in March 12–17, 2019 with the collaboration of Associate Professor Dr. OISHI Takeshi from the Institute of Industrial Science, University of Tokyo (Figure 4.1.10) using a terrestrial 3D laser scanner (Z+F IMAGER® 5010C) by which section and elevation images were created to analyse the structural problems and failure mechanisms of the Gate (Figures 4.1.2-4.1.8).

4.1.2. Damage assessment

For the risk and damage assessment of the existing superstructure, section and elevation images generated from 3D laser scanning data were examined (Figure 4.1.9). This assessment identified three main causes that led to the collapse of the building:

-Partial collapse of the central part of the corbel arch destabilized the remaining part of the vaults, causing them to lean inwards.

-The walls, especially the inside corners, were pulled inwards by the collapsing vaults.

-The outside corners either remained in place or leaned outwards, opening the wall joints.

The detail of damage causes were described in Section 8.1 based on the investigation of the base structure and structural analysis.

4.1.3. Investigation of scattered stones around the East Gate

Before starting the actual restoration work, the stones that fell out of the collapsed structure were documented. The scattered stone specimens around the structure were carefully numbered, examined, and recorded through SfM photogrammetry. Clearly, some scattered stones were arranged on the site at an undetermined point in time, probably during the early 20th century by French conservators. However, no documentation regarding this intervention has been found to date. The scattered stones were in a relatively good condition, and most of them collapsed from the upper part of walls, vaults, or dome-like structure of the East Gate.

The scattered stones were systematically rearranged on the site in May 19–June 13, 2019 by using a spider crane (Figure 4.1.11). New locations of the stones were also documented with SfM photogrammetry, and the number of every stone was recorded. While examining the scattered stones, some specimens of the lost finial (top part of the roof) and south, west, and north pediments were identified, for which trial assembling was performed on site (Figure 4.1.13).

A list of the collapsed stones inside and outside the building is presented in the Tables 4.1.1-4.1.4, and the layout of these collapsed stones is shown in the Figure 4.1.12. In the layout plan, the collapsed stones were coloured according to the identification of the original position: northeast, southeast, southwest, northwest, and central. From this, it was found that

-All the collapsed stones inside building were roof material except two stones from pediment.

-Stones of pediments, pilasters, and parts of the roof were scattered in the area outside the building near the original location.

-Stones from the finial were scattered throughout the area outside the building near the original location.

Most of the roof materials were collapsed inside the building and the pediments were collapsed outside the building, from which it could be concluded that the outercorner stones of the cruciform plan building were moved outwards and the top and innercorner of stones were moved inwards, and collapsed naturally during the long term deterioration.

However, the question remains in terms of the fact that the roof and finial materials in the central part were scattered all around the area outside the building, because if the deterioration over time caused the collapse of these stones, it could be assumed that they would have fallen down inside the building. Thus, it is debatable whether this issue was caused by natural deterioration or human intervention in later periods.

We cannot exclude the possibility of destruction by robbers stealing the treasures embedded around the finial at the time of construction, and it was found that the East Gate had an artificially curved hole with the size of a hand on the top surface of the roof stone. Alternatively, another possibility is that when French archaeologists conducted some research or intervention on the temple at the beginning of the 20th century, they may have reorganised these collapsed stones, as the rearrangement in the past could apparently be observed on site, although it is hard to think that they moved these stones far from their original location.

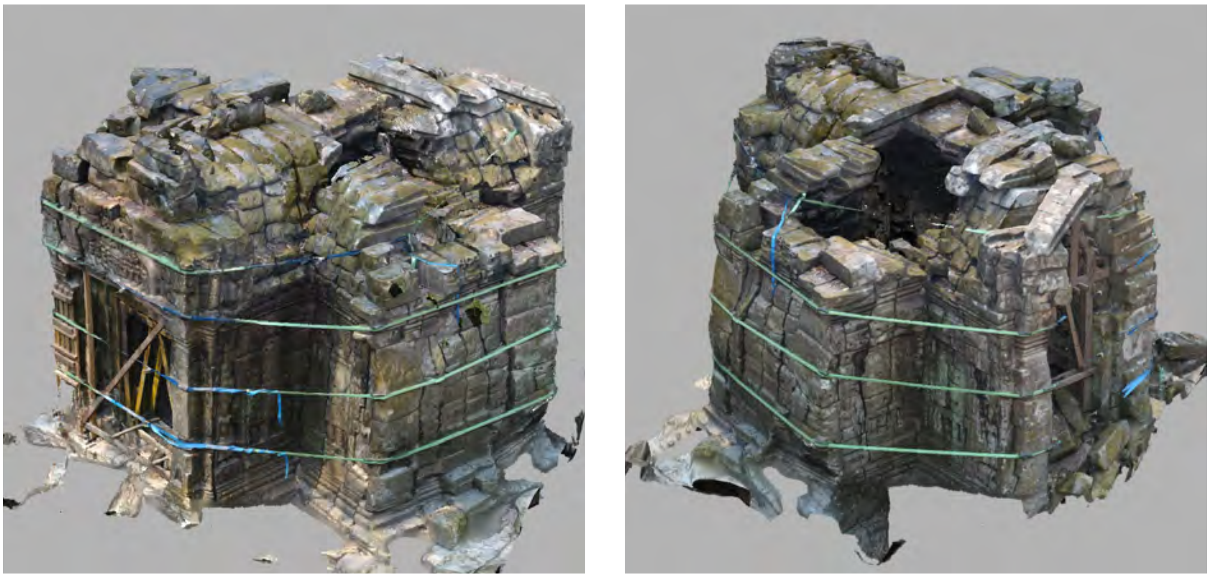


Figure 4.1.1　3D model created from photogrammetry, northeastern view (left) and northwestern view (right)

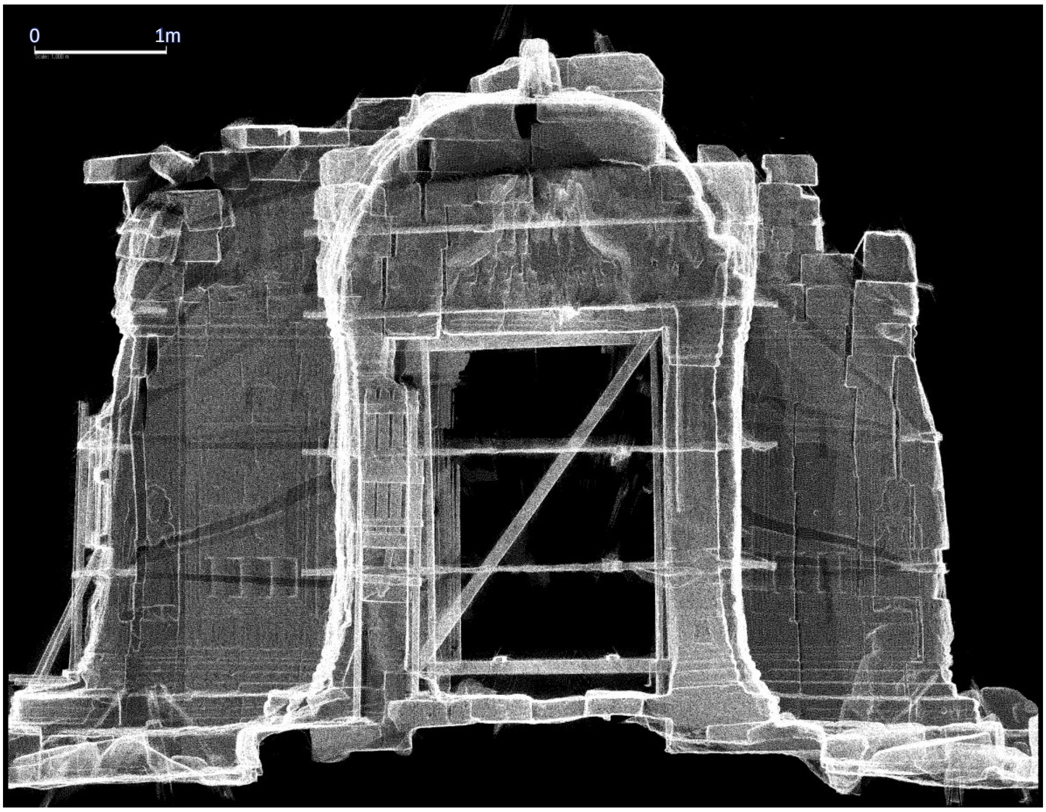


Figure 4.1.2 East elevation created from 3D laser scanning

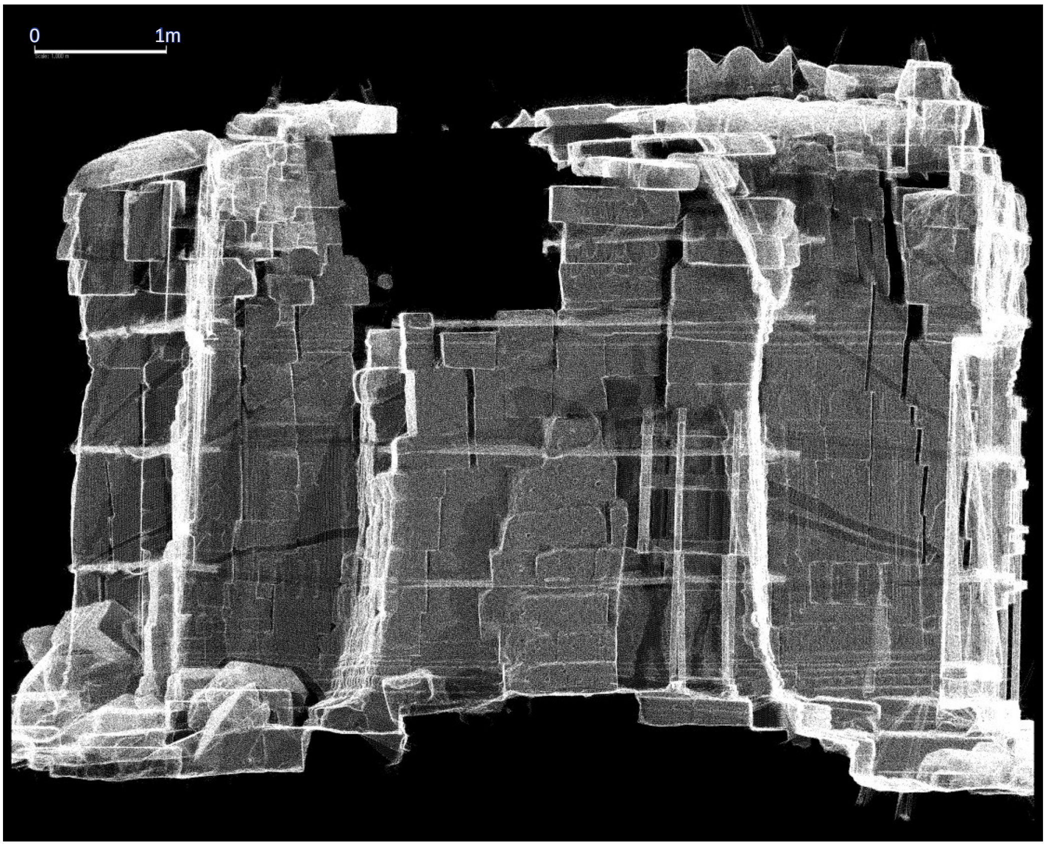


Figure 4.1.3 South elevation created from 3D laser scanning

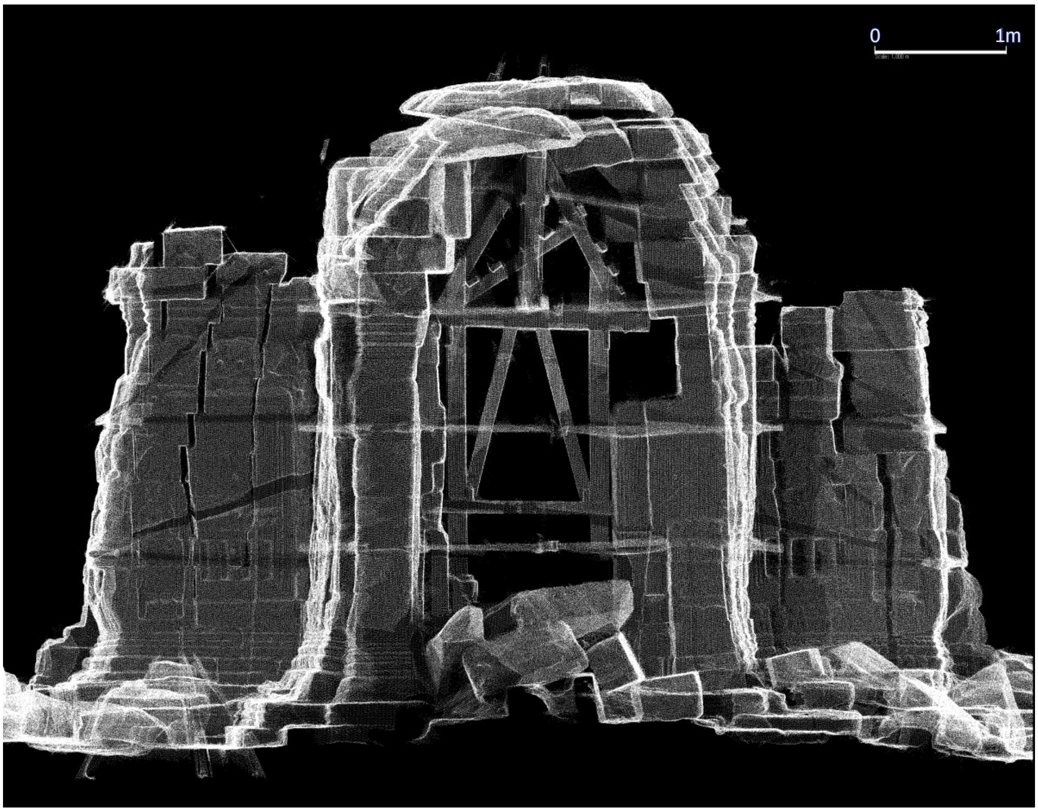


Figure 4.1.4　West elevation created from 3D laser scanning

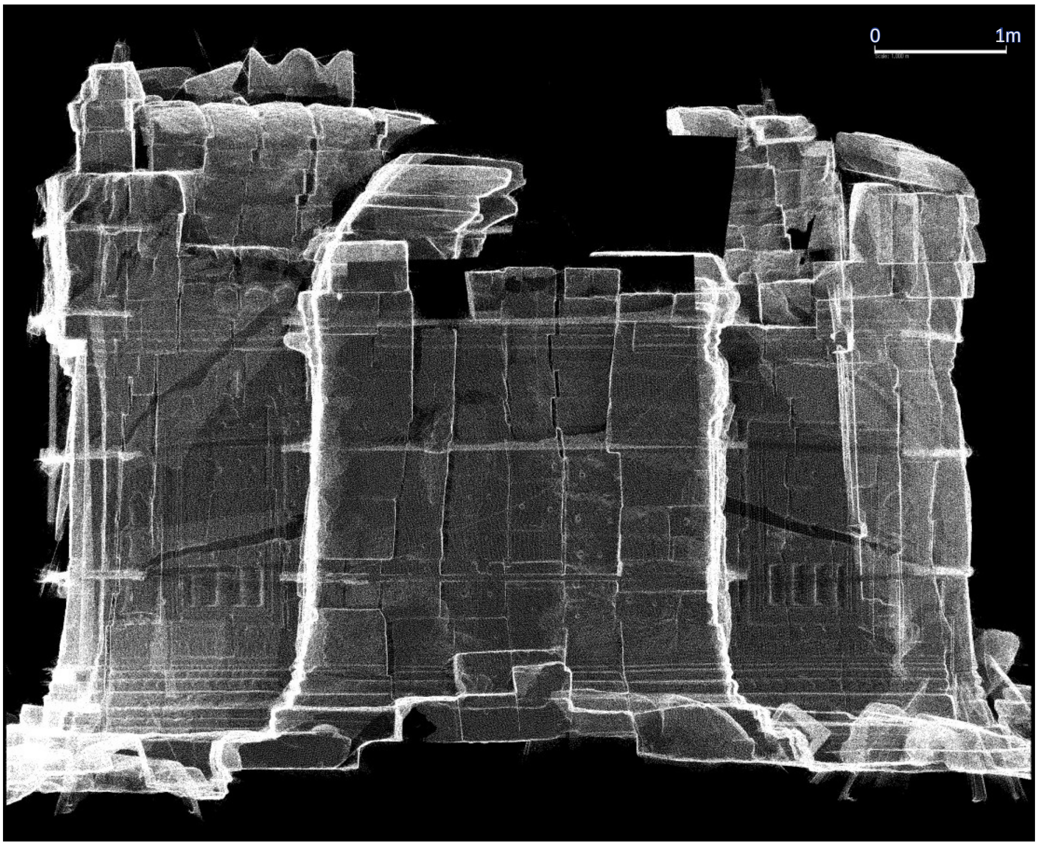


Figure 4.1.5　North elevation created from 3D laser scanning

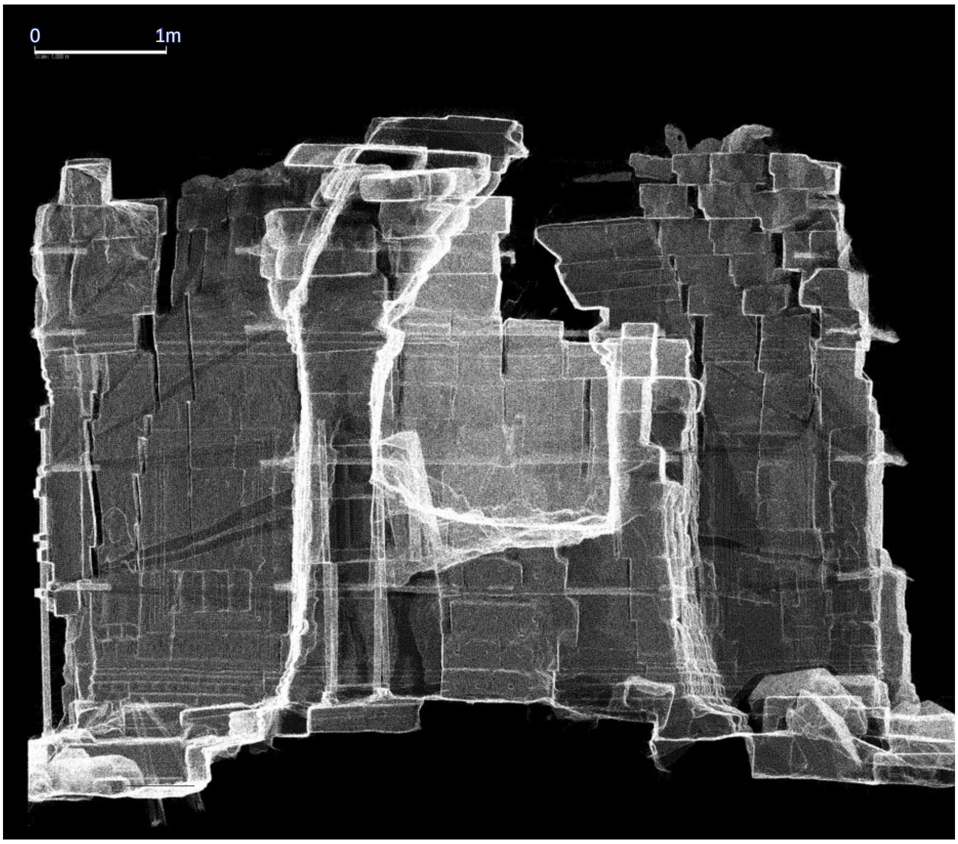


Figure 4.1.6 East-West section created from 3D laser scanning

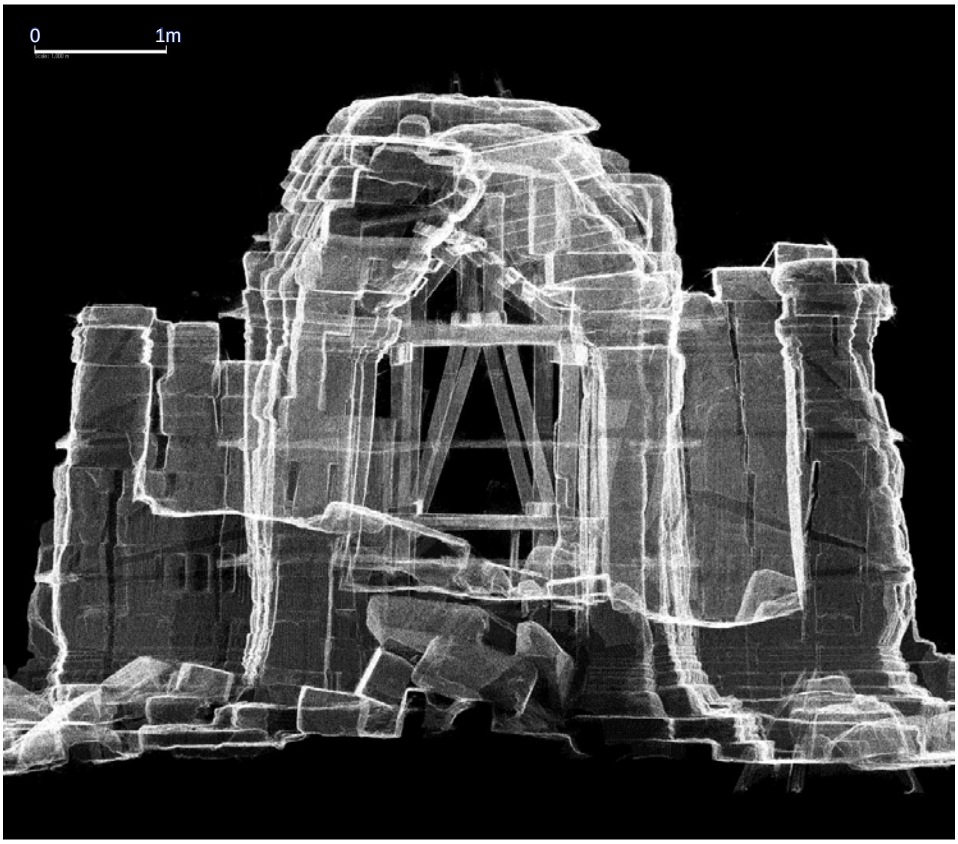


Figure 4.1.7 North-South section created from 3D laser scanning

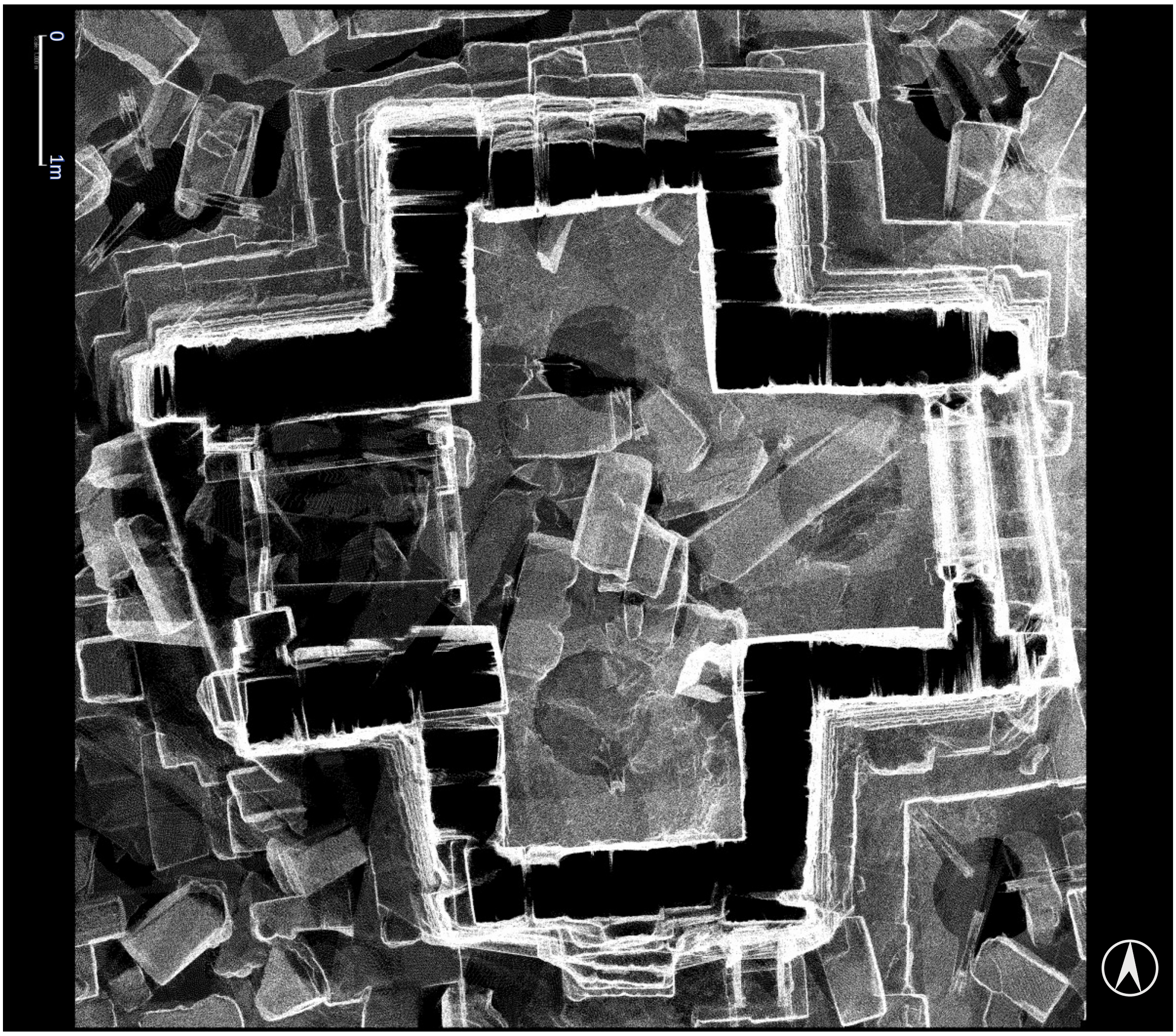


Figure 4.1.8 Plan created from 3D laser scanning

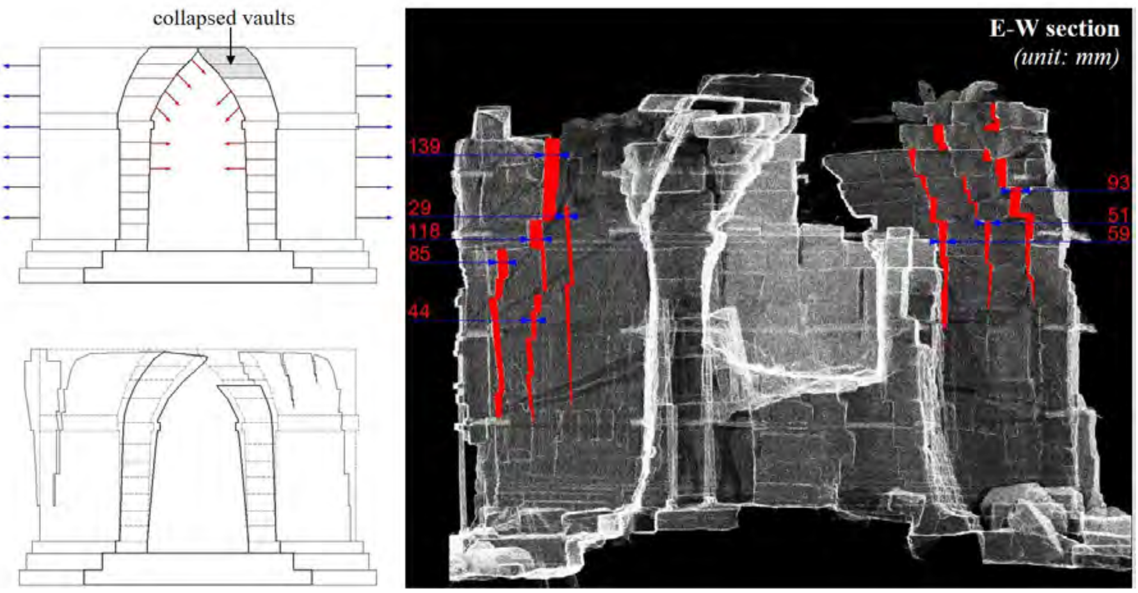


Figure 4.1.9 Example of risk and damage assessment with 3D laser scanning

Figure 4.1.10 3D laser scanning

Figure 4.1.11 Organization of scattered stones using a spider crane

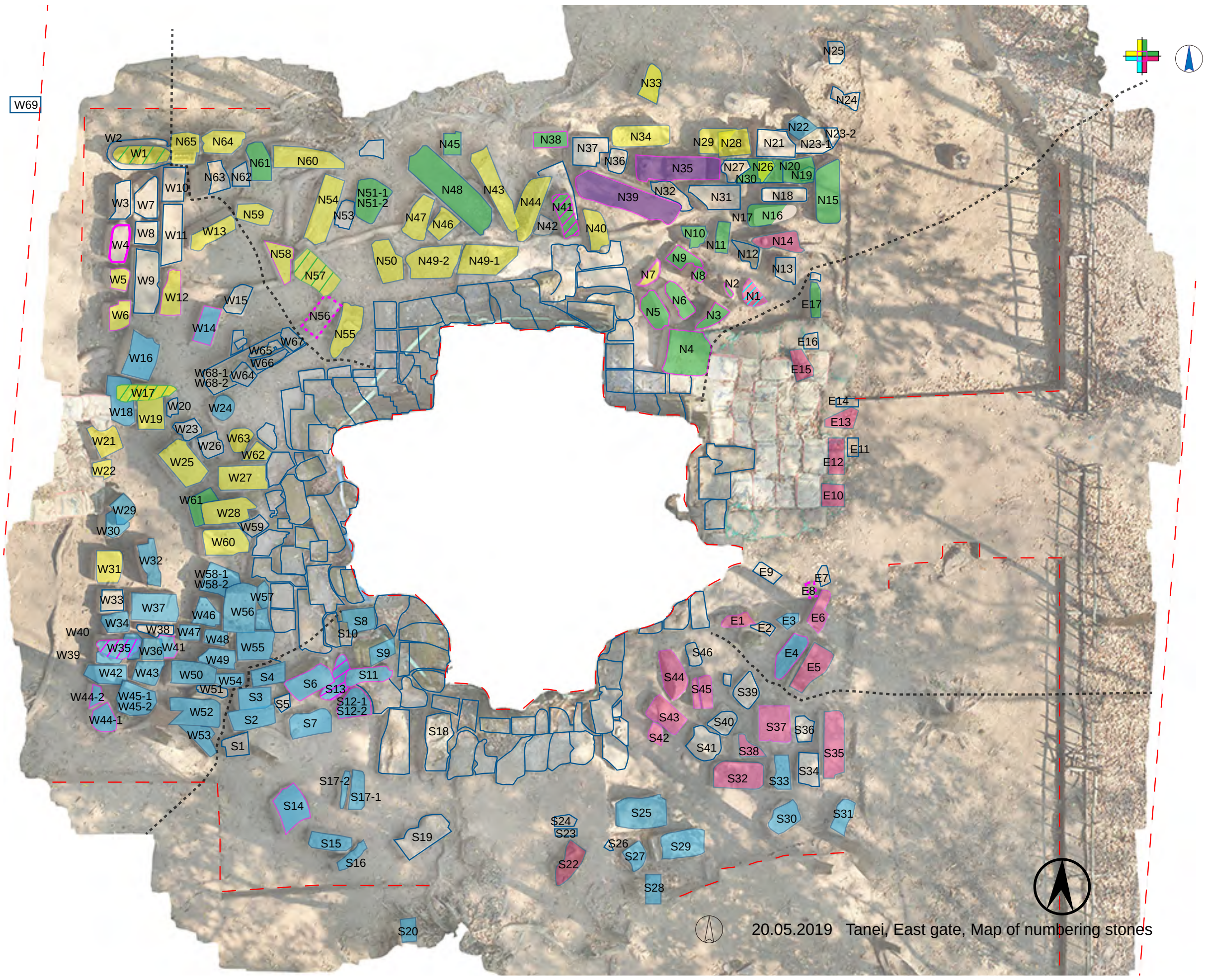


Figure 4.1.12 Documentation of scattered stones around the East Gate (Colouring shows the identified original location of each stone. Northeast: green, southeast: red, southwest: blue, northwest: yellow, unknown: no colour)

Table 4.1.1 List of scattered stones around the East Gate

Temporary Number	Size (mm)			Member	Original Location	Curving
	W	L	H			
E1	370	640	250	Finial	East side (south)	○ Lotus, Cornice
E2	510	380	300	Broken piece		?
E3	250	390	300	Pediment	South pediment (west)	○ Flying Apsara
E4	900	540	230	Finial	South side (middle west)	○ Bottom lotus
E5	340	1030	450	Roof	East side of south wing	○ Roof tile
E6	340	700	300	Finial	Southeast corner	○ Garuda
E7	440	660	180	Broken piece		
E8	180	320	100	Finial?		○ ?
E9	250	770	170	Roof		○ Roof tile
E10	410	360	150	Finial	Southeast	
E11	180	540	210	Broken piece		○ Molding corner
E12	320	870	170	Pediment (upper left	East pediment (south)	○
E13	180	500	360	Pediment (upper left	East pediment (south)	○
E14	430	240	240	?		
E15	320	800	530	Pediment (back left	East pediment (south)	○
E16	160	200	130	Broken piece		
E17	270	800	400	Pediment (back right	East pediment (north)	○
S1	460	350	190	Wall?		
S2	170	800	350	Cornice	Southwest corner	○ Molding
S3	400	610	300	Wall	West side of south wing	○ Window frame
S4	340	620	290	Corince	Southwest corner	○ Molding
S5	290	270	280	?		
S6	490	820	330	Finial	Southwest corner	○ Garuda, floral pattern
S7	480	760	240	Pediment	South pediment (southwest corner)	○ Naga
S8	380	610	230	Cornice	West side of south wing	○ Molding
S9	430	700	350	Cornice	West side of south wing	○ Molding both inside and outside
S10	460	460	230	?		
S11	360	790	290	Finial	Southwest corner	○ Garuda
S12	570	710	310	Finial	West side (south)	○ Bottom Lotus
S13	390	840	170	Finial	South side	○ Middle Lotus
S14	570	740	300	Finial	West side (south)	○ Molding
S15	420	760	290	Pediment	South pediment (southwest corner)	○ Naga
S16	260	730	500	Pediment	South pediment (west)	○
S17	340	700	360	Pediment	South pediment (southwest corner)	○Naga
S18	340	1140	470	Roof ridge	Outer wall?	○
S19	300	1020	450	Roof ridge	Outer wall?	○
S20	390	280	340	Pediment	South pediment (west)	○
S21	140	580	450	Pediment	East pediment (north)	○
S22	360	760	380	Pediment	South pediment (east)	○
S23	410	380	150	?		
S24	90	450	170	Roof		○ Roof tile
S25	1080	550	380	Pediment (left	South pediment (west)	○ Body of Buddhist statue
S26	120	220	200	Broken piece		
S27	390	430	200	Roof	West side of south wing	○ Roof tile
S28	570	360	320	Pediment	South pediment (west)	○ Head of apsara
S29	890	480	360	Pediment	South pediment (west)	○ Head of Buddhist statue
S30	660	450	280	Pediment	South pediment (west)	○ Head of Buddhist statue
S31	640	370	240	Pediment	South pediment (west)	○ Head of Buddhist statue
S32	880	310	450	Pediment	South pediment (east)	○ Flying Apsara
S33	620	330	300	Pediment	South pediment (west)	○
S34	400	590	220	?		
S35	430	1200	280	Roof	East side of south wing	○ Roof tile
S36	430	470	200	?		
S37	570	660	280	Finial	South side (east)	○ Molding
S38	620	260	410	Roof	South side of east wing	
S39	480	540	190	?		
S40	460	460	190	Broken piece		
S41	410	650	310	Broken piece		
S42	290	350	130	Finial	East side (south)	○ Molding
S43	710	380	300	Finial	Southeast corner	○ Garuda, molding
S44	450	820	280	Finial	South side (east)	○ Bottom Lotus
S45	390	620	290	Finial	South side (east)	○ Molding
S46	220	410	200	?		
W1	1020	230	500	Roof ridge	West wing	○

Table 4.1.2 List of scattered stones around the East Gate

W2	1000	460	110	?		
W3	670	410	270	Roof		
W4	720	360	240	Finial?		
W5	410	390	220	Finial	Northwest corner	○ Garuda
W6	580	410	240	Finial	Northwest corner	○ Garuda, molding
W7	800	430	200	Roof? Broken piece		
W8	470	430	240	Broken piece		
W9	1050	500	270	Roof		
W10	610	410	230	?		
W11	1090	420	260	Roof		
W12	850	420	290	Finial	North side (west)	○ Molding
W13	950	290	300	Lintel	West (north)	○
W14	710	360	280	Finial	West side (south)	○ Molding
W15	590	360	150	Broken piece		
W16	830	580	390	Pediment	West pediment (south)	○ Human
W17	830	210	500	Roof ridge	North wing	○
W18	850	480	280	Pediment	West pediment (south)	○
W19	870	480	280	Pediment	West pediment (north)	○ Molding
W20	600	390	240	Roof?		
W21	680	290	520	Pediment	West pediment (north)	○
W22	400	300	140	Pediment	West pediment (north)	○
W23	420	360	220	Broken piece		
W24	500	360	210	Pediment	West pediment (south)	○ Arm
W25	850	530	410	Pediment	West pediment (north)	○ Arm
W26	460	420	290	Wall ?		
W27	860	450	240	Pediment	West pediment (north)	○ Leg
W28	810	410	310	Pediment	West pediment (north)	○ Leg
W29	480	470	250	Pediment	West pediment (south)	○
W30	850	420	260	Pediment	West pediment (south)	○ Leg
W31	520	540	220	Pediment	West pediment (north)	○
W32	800	330	580	Pediment	West pediment (south)	○
W33	460	390	210	Cornice		○ Molding
W34	350	460	260	Lintel	West (south)	○
W35	820	360	150	Finial	South side	○ Middle Lotus
W36	230	410	450	Pilaster	Southwest	○ Dancing person
W37	880	230	500	Pediment	West pediment (southwest corner)	○ Naga
W38	180	300	660	Wall?		
W39	450	470	250	Pilaster	Southwest	○ Molding
W40	410	360	250	Pilaster	Southwest	○
W41	490	410	250	Cornice	West side of south wing	○ Triple circle pattern
W42	770	320	280	Roof	West side of south wing?	○ Roof tile
W43	520	430	270	Roof	West side of south wing?	○ Roof tile
W44	820	440	280	Finial	Southwest corner	○ Bottom Lotus
W45	640	470	330	Pediment	South pediment (southwest)	○
W46	490	470	270	Pediment	West pediment (southwest)	○ Naga
W47	150	360	270	Pilaster	Southwest	○
W48	260	410	180	Pilaster	Southwest	○
W49	660	300	270	Wall	West side of south wing	○ Molding
W50	360	330	820	Pilaster	Southwest	○
W51	590	380	170	Cornice	South side of south wing	○ Molding
W52	510	900	290	Pediment	West pediment (southwest)	○ Naga
W53	340	760	170	Finial	South side	
W54	560	240	190	Pilaster	Southwest	○ Molding
W55	500	670	200	Pediment	West pediment (southwest)	○ Naga
W56	310	930	540	Pediment	West pediment (southwest)	○ Naga
W57	430	470	280	Pediment	West pediment (southwest)	○ Naga
W58	490	670	300	Pediment	West pediment (south)	○
W59	240	410	330	Broken piece		
W60	830	480	320	Pediment	West pediment (north)	○
W61	470	520	290	Pediment	West pediment (south)	○
W62	1000	380	270	Pediment	West pediment (north)	
W63	460	480	240	Pediment	West pediment (north)	○
W64	320	370	280	?		
W65	140	430	110	Cornice		○ Molding
W66	700	280	300	Roof		
W67	420	300	120	?		
W68	1920	460	270	Roof		

Table 4.1.3 List of scattered stones around the East Gate

W69	360	180	160	Pediment?		○ Naga
W80-1	175	350	110	Broken piece		
W80-2	155	260	70	Broken piece		
W81-1	180	365	70	Broken piece		
W82-1	930	355	225	Broken piece		
W83	375	940	240	Roof		
W84	265	940	350	Pediment	West pediment (south)	○
W85	450	500	350	Pediment	West pediment (south)	○ Naga
W86-1	325	440	270	Broken piece		
W86-2	190	275	90	Broken piece		
W87	215	355	90	?		
W88	190	385	150	?		
W89	155	110	130	?		
W90	360	270	60	?		
W91	350	800	260	Pediment	West pediment (north)	○
W92	890	435	220	?		
W93	340	440	300	Lintel	West (south)	○
W94	350	550	290	Pediment	West pediment (south)	○
N1	350	600	180	Finial	South side	○ Top lotus
N2	230	290	120	Finial	East side (middle north)	○ Middle lotus
N3	440	880	320	Finial	Northeast corner	○ Garuda
N4	390	780	300	Finial	East side (middle north)	○ Molding
N5	370	760	200	Finial	East side (middle north)	○ Bottom lotus
N6	340	710	300	Finial	Northeast corner	○ Garuda, molding
N7	240	570	260	Finial	North side	○ Lotus
N8	290	270	260	Pediment	North pediment (east)	○ Naga
N9	330	700	180	Finial	Northeast corner	○ Garuda
N10	560	390	150	Roof	East side of north wing	○ Roof tile
N11	200	530	250	Pediment	North pediment (east)	○ Naga
N12	440	530	160	?		
N13	470	430	120	?		
N14	320	900	150	Pediment (upper left	East pediment (south)	○
N15	240	1180	420	Roof	East side of north wing	○ Roof tile
N16	300	820	160	?		
N17	380	730	240	Finial	East side (north)	○ Bottom lotus
N18	240	800	250	Pediment?		○ (Naga body?)
N19	360	380	210			
N20	400	690	270	Pediment (upper left)	North pediment (east)	○
N21	490	730	140	Roof?		
N22	280	400	430	Pediment	North pediment (east)	○
N23	450	800	250	Roof?		
N24	270	240	530	Colonette		○
N25	360	260	390	Cornice	Other building?	○
N26	370	400	170	Pediment	North pediment (west)	○
N27	380	570	80	Roof?		
N28	600	470	260	Pediment	North pediment (west)	○ Lotus table
N29	450	800	220	Pediment	North pediment (west)	○ Faces
N30	340	1100	280	Roof	East side of north wing	○ (roof tiles)
N31-1	480	970	220	?		
N31-2	360	380	210	broken piece		
N32	280	370	350	Roof?		
N33	600	430	270	Pediment	North pediment (west)	○ Bhuddhist
N34	390	1040	280	Roof	West side of north wing?	○ Roof tile
N35	420	1300	280	Roof	Center	
N36	340	430	210	Pediment		○ Naga?
N37	470	680	210	?		
N38	370	660	290	Finial	Northeast corner	○ Garuda, molding
N39	450	1940	260	Roof	Center	
N40	410	850	250	Roof	West side of north wing	○ Roof tile
N41	270	860	380	Finial	East side	○ Middle lotus
N42	190	280	280	Pediment		○ (floral)
N43	330	1500	280	Pediment	North pediment (northwest)	○
N44	470	1300	330	Pediment	North pediment (west)	○
N45	350	400	180	Pediment	North pediment (east)	○
N46	350	400	250	Roof	West side of north wing	○ Roof tile
N47	380	800	310	Pediment	North pediment (west)	○ Naga
N48	560	1850	330	Roof	East side of north wing	○ Roof tile

Table 4.1.4 List of scattered stones around the East Gate

N49	520	1850	300	Roof	West side of north wing	○ Roof tile
N50	390	850	280	Pediment	North pediment (west)	○ Naga
N51	310	700	340	Finial	East side (north)	○ Molding
N52	470	370	150	?		
N53	320	480	80	?		
N54	380	1200	300	Roof	West side of north wing	○ Roof tile
N55	440	920	380	Roof	West side of north wing	○ Roof tile
N56	400	900	250	Finial?		
N57	340	850	500	Roof ridge	West wing	○
N58	650	560	240	Finial	West side (north)	○ Bottom lotus
N59	350	680	260	Finial	North side (middle west)	○ Molding
N60	400	1350	260	Roof	West side of north wing	○ Roof tile
N61	370	730	180	Roof	East side of north wing	○ Roof tile
N62	370	440	260	roof?		
N63	520	600	460	Pediment?		○
N64	380	780	190	Roof	West side of north wing	○ Roof tile
N65	500	770	480	Finial	East side (middle)	○ Molding
N70	300	1030	540	Pediment	North pediment (east)	○
N71	290	920	390	Pediment	North pediment (east)	○ Naga
N72	320	820	250	Pediment	North pediment (east)	○ Apsara
N73	240	545	410	Pediment	North pediment (east)	○ Leg
N74-1	380	300	140	Broken piece		
N74-2	220	230	50	Broken piece		
N75	610	360	285	Roof ridge		○
N76	335	140	130	Broken piece		
N77-1	390	330	100	Broken piece		
N77-2	220	460	100	Broken piece		
N78	470	470	210	Broken piece		
N79	390	440	130	Broken piece		
N80	280	190	120	Broken piece		
N81	260	240	220	Broken piece		
N82	445	435	120	Broken piece		
N83	550	435	150	Broken piece		
N84	240	120	60	Broken piece		
N85	290	260	100	Broken piece		
N86	130	150	50	Broken piece		
N87	60	80	25	Broken piece		
N88	225	500	150			

Figure 4.1.13 Trial assembling of the pediments and finial

4.2. Dismantlement Work

KANAI Ken, ASADA Natsumi, VAR Elif Berna,
PROM Titchhopnnarith, THAI Yamang, DOY Pichjira

A guideline on the basic policy of restoration, work plan, and schedule were prepared as result of various meetings between APSARA and TOBUNKEN. The description on implementation of each activity are detailed below.

4.2.1. Roof dismantlement

The roof dismantlement started on September 9, 2019 after recording the existing situation of the East Gate, numbering the stones, and drawing the plan of the layer to be dismantled. For stone numbering, the cruciform structure was first divided into four segments with respect to east–west and north–south axes, which intersected at the centre of the gate (Figure 4.2.1). Each existing layer was numbered consecutively starting from the top layer that remained in situ. Then, the stones were identified according to their locations: north (N), south (S), east (E), west (W), northeast (NE), northwest (NW), southeast (SE), and southwest (SW). After indicating the number of layer and location of the stone, each stone at that layer was numbered in clockwise direction. The stones that fell from the roof layers were ignored for numbering. In addition, a stone broken into several fragments was identified by an additional number per fragment at the end. For instance, SE 2/5.1 represents the 1st fragment of the 5th stone in the southeast direction at the 2nd layer. Moreover, the building parts, namely, pediment (P), roof (R), body (B), and foundation (F), were attached to the stone identification. More details on the adopted numbering scheme are provided in Tables 4.2.1-4.2.2 and Figures 4.2.2-4.2.5.

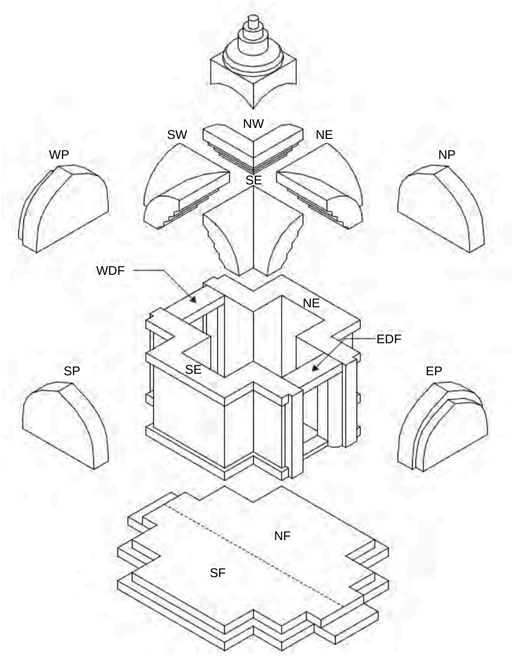


Figure 4.2.1 Stone numbering system

The numbered stones were carefully dismantled by using sling ropes and a crane truck. The dismantled stones were stored in a stone deployment area on the temple site. After dismantling one layer, dismantlement was stopped to proceed with the corresponding documentation. During this stage, the drawing of a new layer was prepared, each stone was numbered, and the SfM photogrammetry of the new layer was documented. Documentation was conducted as soon as the dismantlement of each layer finished. Although most of the stones on the roof were in good condition, some stones were broken into small pieces or cracked.

4.2.2. Cleaning work

When the roof dismantlement was completed on September 20, 2019 (Layer 5), the debris inside the southern part of the gate, constituted by the accumulation of collapsed stones, anthills, soil, and tree roots, were cleaned (Figure 4.2.7). The collapsed stones were carefully removed after numbering. During this process, the fallen stones, almost 70 in total, accumulated in the southern part of the gate were found to had naturally collapsed from the roof or pediment due to aging. In addition, the head of a sculpture with approximately 56 cm height was discovered beneath the collapsed stones leaning against the western wall of the south wing (Figure 4.2.8). The sculpture was presumed to be *Avalokiteśvara* of the Bayon style, and is considered to be valuable as it might shed light on the history of Ta Nei Temple, which remains unknown. After detailed documentation using 3D laser scanning and photography, the head was brought to museum storage for further investigation (Figure 4.2.9). In addition, the condition of the newly unveiled interior walls and floor were documented at this step by using a 3D laser scanner (FARO Focus 3D Laser Scanner) and SfM photogrammetry in October 7–9, 2019.

4.2.3. Wall dismantlement

After the cleaning and documentation works, wall dismantlement started from layer 6 on October 16, 2019 and stopped at layer 16 on November 4, 2019. Unlike roof dismantlement, the wall stones were lifted slightly with a stone clamp and then placed on wooden planks for easily replacing the clamp with sling belts. After checking the condition and fixing the length of the belts, the stones were lifted again and stored in the stone deployment area. The stone numbering system of the wall was also slightly different from that of the roof. Only north and south directions were used in this case, as there were no missing stones on the wall layers. Depending on the location, the stones were named as NB or SB, denoting north or south body, respectively. For instance, NB 12/4 represents the 4th stone from the left side of the structure in clockwise direction in the wall stone located at layer 12 on the northern part of the structure. The dismantled stones were documented three times: before, during, and after dismantlement. It was confirmed during this process that tree roots, snails, and insects, particularly ants, negatively impact the conservation of stones in the East Gate.

4.2.4. Documentation and stone inventory

Documentation was simultaneously conducted with each step of the dismantling process detailed above. Specifically, before starting the dismantlement of each layer (both for the roof and walls), elevation photos from eight directions were taken in addition to the plan photo taken with a 4.5 m pole for SfM photogrammetry. Every stone was photographed before, during, and after its dismantlement. The dismantled stones were stored in the stone deployment area, and SfM photogrammetry of the deployment area was obtained with the numbers indicated on every stone. Proper space was maintained between each stone for individual inventory and securing maneuverability. As part of stone inventory, the size, physical condition, connecting points for stone fragments/breakings, existence of carvings, and any other remarks were noted in the English and Khmer languages.

Table 4.2.1　Stone numbering system for dismantlement of in-situ stones

Location of Stone	Numbering	Example
Roof	Each roof layer was divided into four locations: north (N), south (S), east (E), west (W)/northeast (NE), northwest (NW), southeast (SE), and southwest (SW). After indicating the location of the stone, the number of the layer was written as numerator and that of the stone as denominator. In addition, if the stone was broken into fragments, they were shown with sequential numbers after the indication of the stone number by adding a period and identifying the fragment.	NW1/1, NW1/2.2, ...
Pediment	For numbering the pediment (P), the location of the stone was denoted as north (N), south (S), east (E), or west (W) followed by Letter P. Similar to the numbering for the roof, the number of the layer was written as numerator and that of the stone as denominator.	EP1/1, EP1/2, ...
Wall	Wall layers were divided into two locations: north (N) and south (S) divided by the east–west axis. Letter B was added after the location, representing the word "body." The numbers of the wall layers were the continuation of the roof layers. The number of the stone in the denominator was counted in clockwise direction (i.e., from west to east for stones in the north, and from east to west for those in the south).	NB7/1, NB7/2, ...
Door frame	The components of the east and west door frames were indicated by DF preceded by the location, east (E) or west (W).	EDF1.1, WDF1.2, ...
Floor	The floor was also divided into north (N) and south (S) locations with respect to the east–west axis. The same numbering was used for the dismantlement of floor stones. Like for the other layers, the layer numbers were the continuation of the roof layers.	NF17/1, NF17/2, ...
Base structure	The base structure (B) was divided into north (N) and south (S) locations with respect the east–west axis. The number of layers were the continuation of the roof layers, but only the dismantled part was numbered. The number of the layer was written as numerator, and the stone was identified in the denominator using a lowercase letter.	NB17/a, NB17/b, ...

Table 4.2.2　Stone numbering system for dismantlement of ex-situ stones

Location of Stone	Numbering	Example
Scattered stones ※ Temporary numeration	The scattered stones around the gate were numbered according to the area in which they were found. The site was divided into four locations: northeast (NE), northwest (NW), southeast (SE), and southwest (SW). The location of the stone was written followed by its number.	NW1, NW2, ...
Stones found inside the gate ※ Temporary numeration	Abbreviation EGC (East Gate Central) was used to indicate stones found inside the gate. It was followed by the number of the layer (1st layer represented by・ı・ and 2nd layer by・r・) and the order of relocation of the stones.	EGC・ı・1, ... EGC・r・1, ...

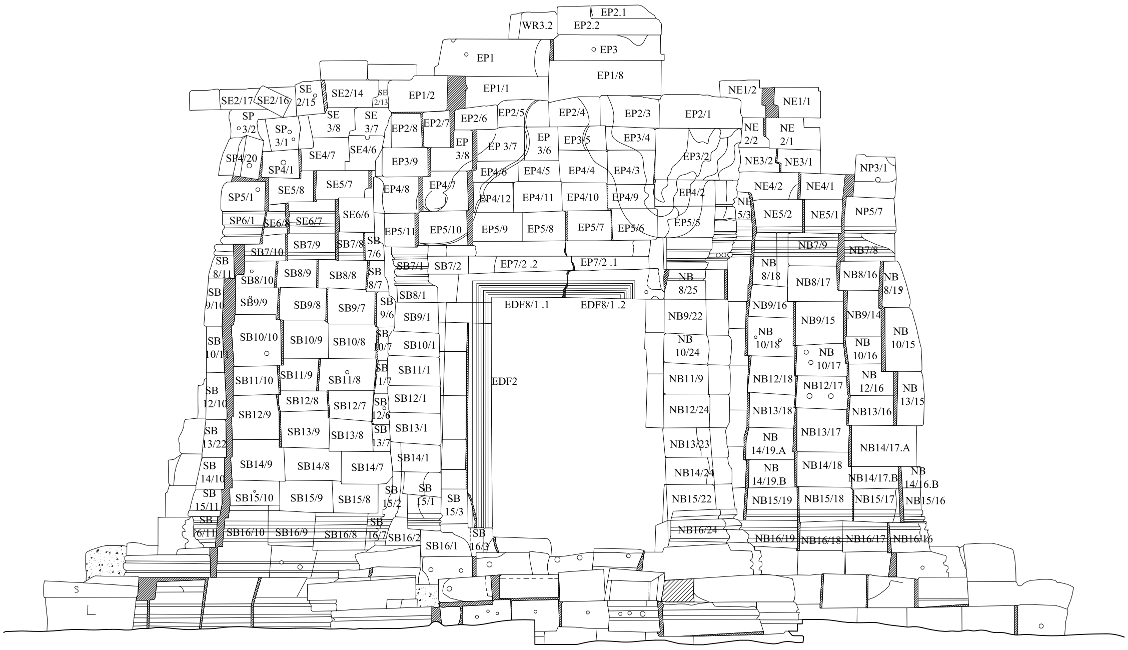


Figure 4.2.2 Numbering map of the east elevation

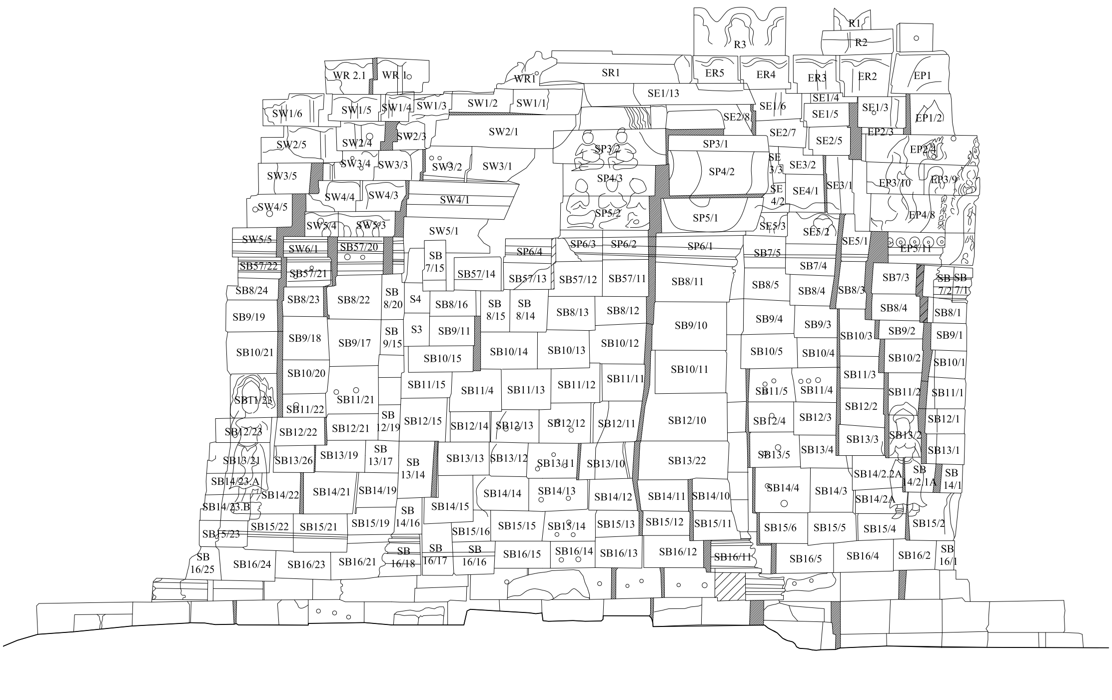


Figure 4.2.3 Numbering map of the south elevation

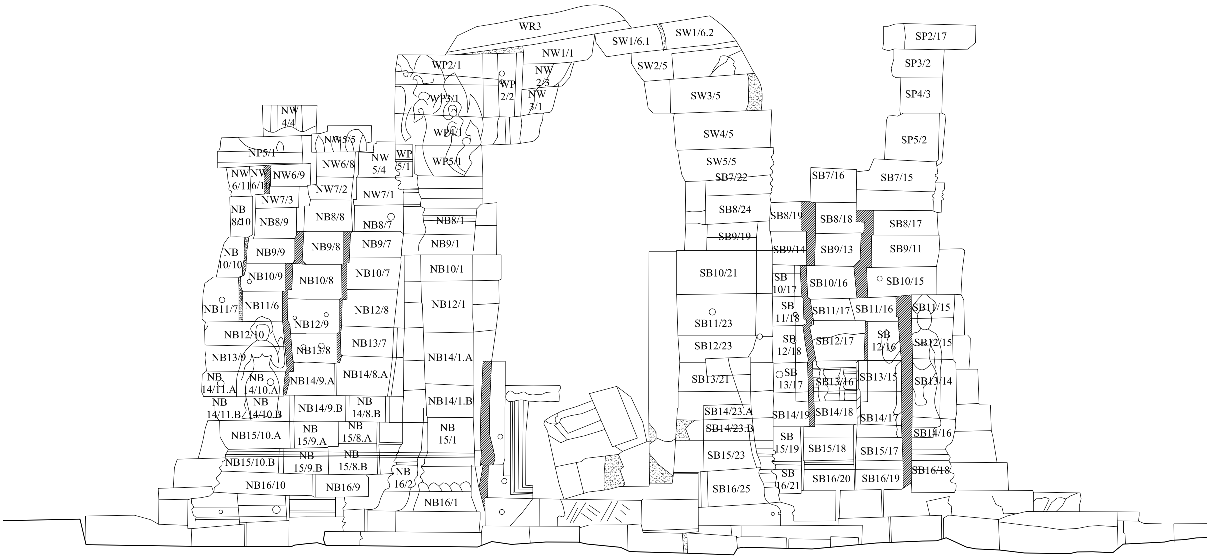


Figure 4.2.4 Numbering map of the west elevation

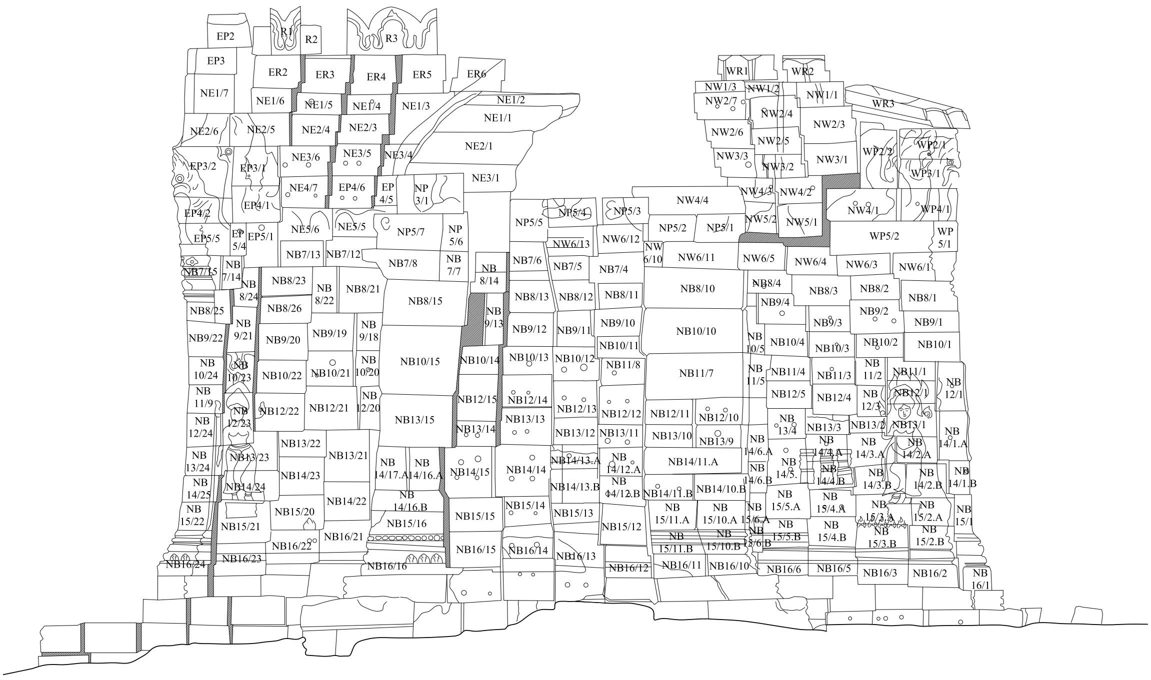


Figure 4.2.5 Numbering map of the north elevation

Figure 4.2.6 Dismantlement of roof structure using a crane truck

Figure 4.2.7 Cleaning work inside the East Gate

Figure 4.2.8 Head of sculpture in-situ, which is assumed to be *Lokesvara*

Figure 4.2.9 Head of sculpture, trihedral photography (by courtesy of APSARA)

Chapter 5

Investigation of the Construction Method

5.1. Archaeological Investigation of the Base Structure

ABE Masashi, KANSHA Hiroo, SEA Sophearun, SITHA Visaraboth

(1) Aims of the investigation

After dismantling works from August to November 2019, the East Gate was left only with its base structure. Since unevenness among the base structure's members had been recognised, it was necessary to identify its cause and make improvements before starting the reassembly work of the superstructure. Excavation survey and partial dismantlement of the floor materials to check below and inside the structure were conducted December 2–20, 2019.

After establishing four 5-by-5 m grids around the East Gate for the investigations (Figure 5.1.1), excavation was carried out to reveal the original ground level. Furthermore, the southeastern and northwestern areas were dug deeper to reach the bottom of the stone foundation structure.

Figure 5.1.1 Excavation area

(2) Revealing the original ground surface

The original ground surface was unearthed just a few centimeters below the present surface, since the soil around the East Gate had already been taken away when scattered stone materials there were removed in the period from August to November 2019. Soil composing the original ground was quite compact and included many sandstone chips.

(3) Two deep soundings

1. Southeastern sounding

A sounding of one-meter square was set on the southeastern corner of the East Gate to reveal the bottom of the stone base structure. It revealed an underground structure consisting of a course of sandstone above the bottom laterite course. The bottom course was set about 55 cm below the original ground surface, protruding about 30 cm from the face of the sandstone materials above it (Figure 5.1.2-5.1.3).

The character of the leveling soils below surface corresponded to stone materials: many sandstone chips were contained in the soil about 25 cm below the surface, which was the bottom level of the sandstone materials, while laterite chips were included in the soil below. This phenomenon may be explained as chips mixing into the local soil when stone materials were shaped for construction use on site. Furthermore, the soil itself was very compact and viscous. Therefore, this soil was chosen, and chips were retained deliberately to prevent sliding of the stone foundation structure of the East Gate.

A top of compact sand layer including few chips was revealed below the bottom level of the stone base structure. A similar layer had been unearthed below the original approach way between the Terrace on the Western Embankment of the East Baray and the East Gate, which was investigated in 2018. This layer would be the sand foundation commonly used for Ta Nei Temple.

2. Northwestern sounding

Another sounding measuring 1 m by 1 m was opened on the northwestern corner of the East Gate (Figure 5.1.4). The East Gate's sand foundation was revealed 80 cm below the ground surface of the Angkor period. This sand foundation is compact and consists of alternating layers of yellowish orange (10YR 8/8) sand and light grey (2.5Y 7/1) sand. Each yellowish orange layer is approximately 1.5 cm thick, while each light grey layer is approximately 0.5 cm thick (Figure 5.1.5).

On this sand foundation, the stone base structure was constructed. The underground stone base structure is composed of three or four courses of roughly shaped stones. The lowest course consists of laterite blocks while the upper courses consist of sandstone blocks. The stone blocks are roughly shaped and have no moldings because the underground stone foundation was buried and therefore invisible during the Angkor period. The soil surrounding the underground stone base structure was filled with laterite and sandstone debris.

Figure 5.1.2 Southeastern sounding facing west

Figure 5.1.3 Southeastern sounding facing north

Figure 5.1.4 Northwestern sounding facing east

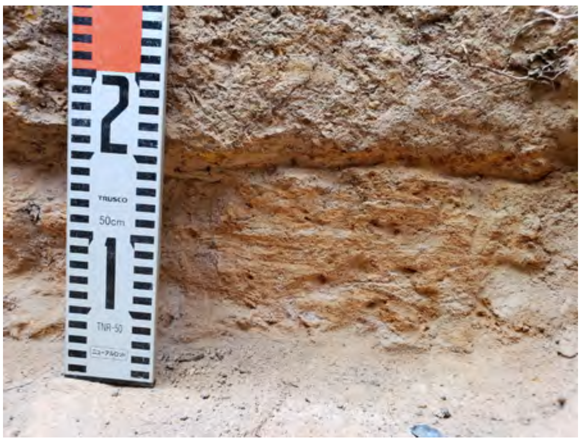


Figure 5.1.5 Alternating layers of yellowish orange sand and light grey sand below the stone base structure

5.2. Construction Method

ASADA Natsumi, SEA Sophearun

5.2.1. Construction methods of the East Gate

(1) Processing sandstone materials

The Ta Nei East Gate uses laterite and compacted soil entirely inside the sandstone outfits of the base structure and floor pavement, but other structural parts comprise sandstone. The processing quality of the sandstone exterior wall surfaces varies with locations, and is not homogeneous in some parts. The engravings on the pediments were carefully made and exhibited a high degree of perfection, but it would seem that the engraving work was suspended midway in some places, such as the false window and cornice. However, many of the joints between the sandstone blocks confirmed during the dismantling had been carefully polished and finished to avoid creating gaps.

Such processing traces were surveyed in parallel with the dismantling work. Nevertheless, the field survey had to be suspended owing to COVID-19 travel restrictions. While the upper surface and some sides of the stones that form the wall sandstone were investigated, the undersides and sides of the stone's contact surface remained unidentified. Although the surveyed data are incomplete, a summary and considerations vis-à-vis the processing traces that could be investigated are presented below.

1. Types of processing traces

There are three types of processing traces on the upper portion of the contact surfaces of 475 sandstone blocks (layers 7-17) constituting the walls (Figure 5.2.1).

A: Linear traces

A linear trace approximately 30 mm long was often observed. It is assumed that it was made by a flat-bladed chisel or an adze-like tool. There is a slight angle in the incidence of the blade. It is not possible to tell from the traces whether it was double-or single-edged.

B: Punctate traces

There are three types of punctate traces: 1) punctate traces with a diameter of approximately 3–7 mm on the surface of the stone; 2) traces with a length of about 10–30 mm drawing a tail from the point; 3) traces of intermediate shapes between the first two. All of them are assumed to be processing traces from a tool such as a round chisel with a sharp tip in the shape of a pencil. These differences are likely

Figure 5.2.1 Three types of traces found on the upper surface of wall sandstones (Left: Linear traces; Middle: Punctate traces; Right: Abrasive traces)

the results of differences in the size and use of the tool.

C: Abrasive traces

There are polishing traces from smoothing the sandstone surface.

In some cases, there is only one type of processing trace on one connecting surface; in others, there are several types. Linear traces appear most frequently on the upper parts of the connecting surfaces. On surfaces where linear and punctate traces are mixed, they tend to be mixed without overlapping.

First, it seems that a flat-bladed tool and a round chisel were used to produce an approximate plane, which was then polished to allow the stones to be in close contact with each other either by rubbing them against each other or by using a whetstone or sandstone. Parts too hard to process protruding from the surface of the stone bear traces of attempts at removing them with a round chisel.

Thus far, only a few tools used during the Angkor period have been discovered. In a survey conducted by the JSA from 1996 to 1999 on the restoration of the Bayon northern library, a chisel was found under the sandstone of the floor at the centre of the northern library's base structure (JSA, 2000: 363-364), exhibiting a total length of 149 mm, a diameter of approximately 20 mm, an irregular circular handle, and a pyramid-shaped iron round chisel at the tip. An irregularly shaped hemispherical sandstone with a smooth surface was found in the soil at the western causeway to Angkor Wat, which was assumed that it was a whetstone used for stone processing (Katagiri, 2003). At the site of a bronze processing workshop in Angkor Thom, bronze statues and other materials were found along with tools appearing to be iron chisels, although the use of those chisels was unidentified (Polkinghorne et al., 2014).

2. Processing quality

Many of the upper surfaces of the wall sandstone were confirmed to have been smoothed by polishing so that almost no linear or punctate traces remained (Figure 5.2.3). However, although the upper surfaces of the connections at the top level of the foundation (=floor level) were finished flat to remove all gaps between the sandstone blocks, linear and punctate traces remain on the connection surfaces, with only a few having been polished to the extent that they disappear. Careful polishing of the connection surfaces increases the contact area and improves the friction force between the stones. There is a possibility that the connection surfaces may have been deliberately and carefully finished at the area where the arch thrust is increased.

In terms of processing quality, many of the upper surfaces of the sandstone blocks were polished and smoothed. While the side surfaces tend to have been smoothed, they have groove-like traces in the longitudinal direction, with far fewer polished traces than the upper surfaces. The prevailing theory is that the stone structures of Angkor were constructed with no joint material while rubbing the sandstone blocks together (Dumarçay, 2001; Akazawa, 2015), but the differences in processing accuracy between the upper and side surfaces as confirmed here seemingly indicate that the sandstone blocks may have been shaped prior to stacking. In addition to this, the connection side surface is slightly retracted than the finished interior surface, which means that the mutual stone rubbing technique did not seem to work here (Figure 5.2.5). As there are few survey samples to compare the processing traces on the side and lower surfaces of the stones, we shall not take this discussion further than stating the possibility here. This can be revisited if there are opportunities to survey other dismantling sites in the future.

In Layer 17 (top of the foundation = floor level), the processing quality of the sandstone directly under the walls bearing the load of the superstructure was compared with that of the side surfaces of the floor sandstone laid in a cross-shaped plane. The sides where the sandstone blocks that bear the load of the superstructure touch each other are smooth, albeit with linear traces remaining, and the sandstone blocks are kept together without gaps. Conversely, looking at the connection surfaces of the floor sandstone blocks, the processing traces are rough, with some of them exhibiting chiselled finishes (Figure 5.2.4). In short, the processing quality of the connection surfaces differs between the sandstone blocks directly under the walls, which are load bearing materials, and the floor sandstone blocks, which are part of the interior design. This suggests some possibilities, including the following. First, the processing precision was intentionally adjusted based on the function of the sandstone blocks, such as whether the surfaces are nearly invisible or clearly visible, whether materials have structural or aesthetic functions, and the conditions at the time of construction. Second, this may be an inevitable consequence of the construction procedures. It was possible to view the stones sequentially and adjust them carefully while observing the vertical connections of the outer periphery stone at the floor level. However, it was difficult to do so at the centre of the floor, forcing workers to drop the stones into the floor towards the end—the processing precision could not but decrease.

(2) White substance found at the connection surface in-between sandstone blocks

Some of the white substance was found adhered to the upper surfaces of the connections in-between sandstone blocks (Figure 5.2.6). In the upper parts of the walls (Layers 7–11), the white substance was found on 20–40% of the stones' upper surfaces in each layer; in the lower part of the walls (Layers 12–16), it was found on more than 50% of the stones' upper surfaces. In most cases, the white substance is not thick but only thinly adhered to the stone surface. However, in some places, it has a maximum thickness of approximately 2 mm. The planar shape is irregular, the range of spread is different, and there is no regularity of planar arrangement or relationship with types of processing traces.

It is generally believed that the sandstone structures built in the Angkor period are more or less stacked without the use of joint materials. Scientific analysis was conducted to verify the possibility that this white substance was artificially applied as a smoothing agent or a temporary adhesive for setting stones. The results of the analysis are described in detail in Chapter 7. In summary, the components of the white substance were calcite and soil, and no contamination of organic matter was confirmed. Overall, including the residual conditions, it is possible to assume that the white substance is deposited from the sandstone. Dumarçay made an interesting point on this.

'Once removed from its bed, sandstone loses the water it contains owing to evaporation. It brings to surface a part of the cement that binds together the grains that make up the stone. This cement is left on the surface of the block and forms a hard crust after a month or two.' (Dumarçay 2005: 63)

Dumarçay also stated that the deposition of the white substance stops once the evaporation is complete. It would seem that the white substance confirmed here was deposited from the sandstone and remained in the small gaps between the connecting surfaces. The remnants of the white substance on many of the stone connections in the East Gate may prove that the building was never dismantled since its construction.

(3) Construction techniques

The construction techniques of the East Gate identified during the architectural survey at the time of the dismantling, the penetration test of the foundation, archaeological survey, and reassembling work are described below.

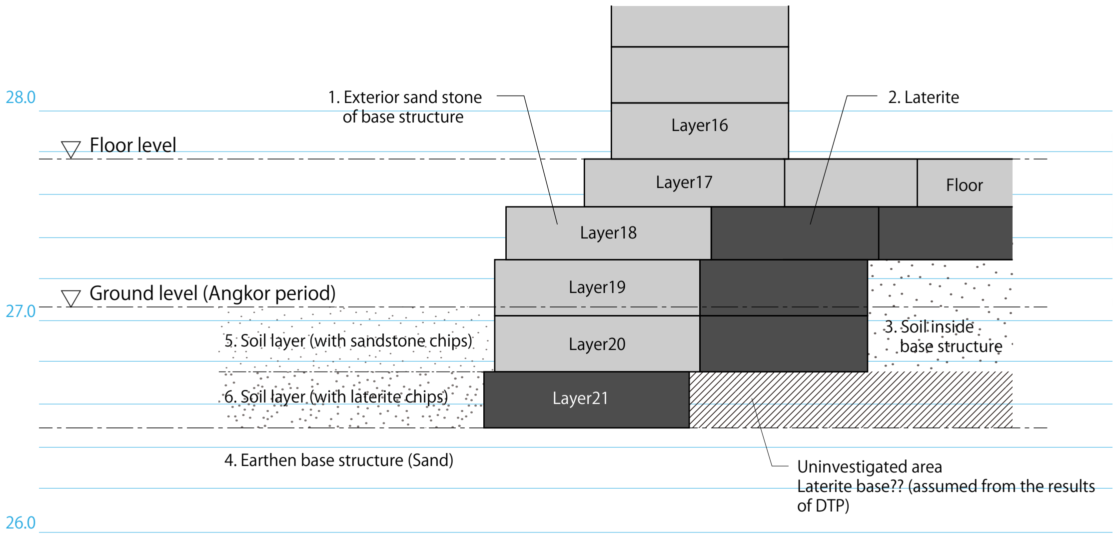


Figure 5.2.2 Diagram of the base structure's constitution (eastern side)

Figure 5.2.3 Smoothed upper surfaces of the sandstone wall

Figure 5.2.4 Difference in processing precision

Figure 5.2.5 Connection side surface is slightly retracted than the finished interior surface

Figure 5.2.6 White substance adhered to the sandstones' upper surfaces

1. Foundation soil below the base structure

The excavation outside the base structure, described in Section 5.1, found part of the compacted sandy soil layer. The layer was located directly below the laterite at the base's bottom, compacted by alternating layers of 15 mm thick yellowish-orange sand and 5 mm thick light-grey sand. However, as the survey area was 1 m^2 outside the inner corner of the cruciform planned base structure and about 15 cm deep from the bottom of the base, it was not possible to confirm the overall picture of the foundation soil layer or its planar extent.

2. Base structure

The masonry base structure stands atop the foundation of compacted soil layer. Looking at the configuration of the base structure, laterite ('base laterite') is placed on the periphery of the cross-shaped plane at the bottom, on top of which sandstone serving as the foundation's exterior ('exterior sandstone') is piled. Subsequently, laterite serving as the substrate for the sandstone ('laterite substrate') is placed with the short sides lining up with the exterior sandstone outside, within which a layer of compacted soil can be found further in (Figures 5.2.2, 5.2.7, and 5.2.8).

In the survey accompanying the partial dismantling of the foundation, it was confirmed that there were places where the substrate laterite inside the foundation rested on the exterior sandstone beneath and places where there had never been any substrate laterite so that the exterior sandstone and the internal compacted soil were adjacent to each other (Figure 5.2.9). In other words, in some places, the substrate laterite alone did not function as a frame for the internal compacted soil. Based on these findings, we may assume that the East Gate base structure was constructed initially as follows.

First, the base soil layer was made by alternatingly compacting different types of sandy soil to form a compacted soil layer. On top of that, base laterite blocks were placed with visible edges on the periphery of the cross-shaped plane (Layer 21). As it has not been possible during investigation to visually confirm whether the bottom base laterite covers only the periphery of the cross or whether it also covers the inside of the cross-shaped plane. However, the penetration test at the centre of the foundation revealed the existence of a layer that is too hard to penetrate under the internal compacted soil layer at a depth of 0.7–1.0 m (elevation 26.8 m and 26.5 m) from the floor surface. This corresponds to the level of the upper surfaces of the bottom base laterite at Layer 21. It is assumed that the base laterite covers the inside of the cross-shaped plane at Layer 21.

On top of the base laterite, the exterior sandstone was made to line the periphery of the cross-shaped plane, their edges facing outwards. While doing this, the outer edges of the exterior sandstone were placed dozens of centimetres inwards from the outer edge of the base laterite. The substrate laterite was placed within the exterior sandstone, with sandy soil compacted inside to form a compacted soil layer. This procedure was repeated to create two layers above. For Layer 18, laterite was made to cover the entire inside of the exterior sandstone. This makes up the substrate for the floor sandstone. At the top level of the foundation—the floor—the ends of the exterior sandstone were pulled inwards from the lower ends, with the wall sandstone stacked directly above. The floor sandstone was laid within the exterior sandstone (Layer 17). At the top of the foundation, there is a place where a part of the sandstone directly beneath the walls come under the floor stones (Figure 5.2.10), which shows that the order of the construction started with lining up the exterior sandstone directly beneath the wall, followed by the arrangement of the floor stones. Sandstone blocks of various thicknesses were used for the flooring. To ensure that the upper surfaces of the floor sandstone are horizontal, the floor stones were placed by scraping the floor substrate laterite or inserting something between the flooring sandstone blocks and the substrate laterite to adjust the unevenness. Soil mixed with a large amount of sandstone and laterite chips was used to adjust the unevenness; notably, the size of these chips varied according to the adjustment height (Figure 5.2.11). This method of adjusting unevenness was used only at the centre of

Figure 5.2.7 Connections between the exterior sandstones and substrate laterite

Figure 5.2.8 Base laterite and substrate laterite

Figure 5.2.9 Absence of substrate laterite

Figure 5.2.10 Exterior sandstone placed under floor sandstone

Figure 5.2.11 Material used to adjust the floor sandstones' unevenness

Figure 5.2.12 A gap filled with an adjustment material comprising soil mixed with either sandstone or laterite chips

the floor where no upper wall load falls, without any confirmed adjustment directly beneath the walls.

This describes the basic structure, but as mentioned previously, some places exhibit exceptional placements. For example, the substrate laterite supposed to be inside the exterior sandstone is partially missing at the eastern entrance, replaced with compacted soil, perhaps from the initial construction, with the effect that the exterior sandstone and internal compacted soil are in direct contact. Immediately beneath the wall in the southwestern inner corner, a gap of approximately 200 mm by 300 mm between the floor-level exterior sandstone had been filled with an adjustment material comprising soil mixed with either sandstone or laterite chips (Figure 5.2.12). A gap filled with the same adjustment material was found in an invisible section directly beneath the wall. The use of this adjustment material appears to indicate that having some lacunae in the invisible sections was not assumed to influence the overall structural stability much, even with the replacement of inferior strength by soil.

3. Walls

The walls comprise piled-up sandstones showing the shorter sides of stone blocks. As with other structures built in the Bayon style, the sandstone blocks that compose the East Gate building are smaller than those of earlier Angkor structures.

Figures 5.2.15-5.2.17 show the assumed order of construction based on the examination of the stone joints. Although it seems that there are many directions in which the cross-shaped plane can be stacked from the inner to the outer corners, there was not necessarily any regularity in this, as there are layers that start from near the outer corners or near the ends (opening frames). Of the outer and inner corners, only the northeastern inner corner used a technique by which the stones are stacked alternatingly layer by layer. Nonetheless, the other corners are not particularly regular in their stacking, with many places having vertical joints passing through. At the end of the outer corner of the northern and southern wings, the long sides were stacked facing the gable side, and the shorter sides were facing outwards at the centre of the gable wall of both wings. As no attention was paid to the potential scraping off of engravings finished after the stone construction, the sandstone at the outer corners tends to be extremely thin (Figure 5.2.13). Irregular deformation can be observed at the northern gable wall, with the stone at the end of the outer corner being displaced outwards and the central part sloping inwards.

Figure 5.2.13 Extremely small sandstone at the base structure's outer corner

Figure 5.2.14 Stone joints at wall corners

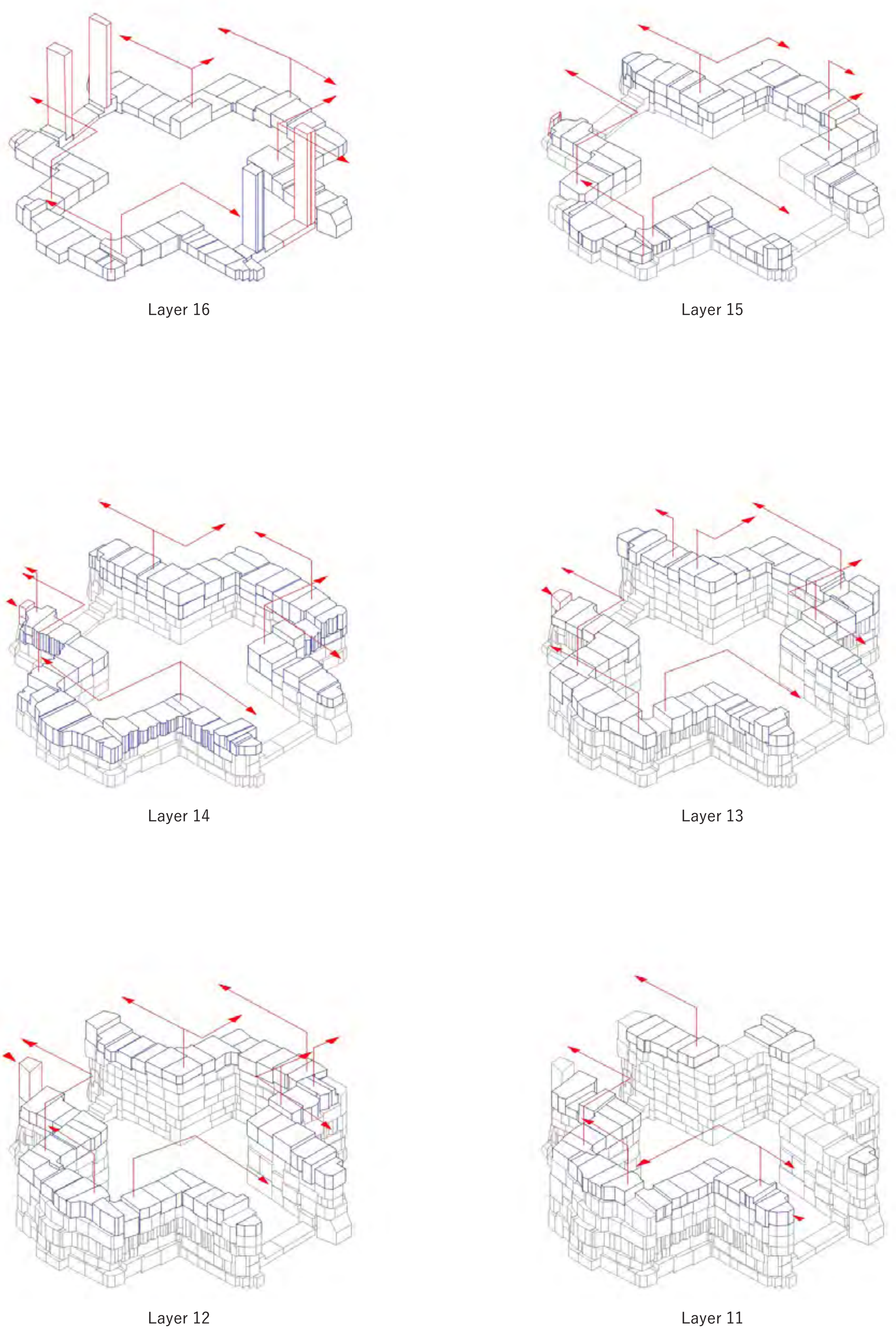
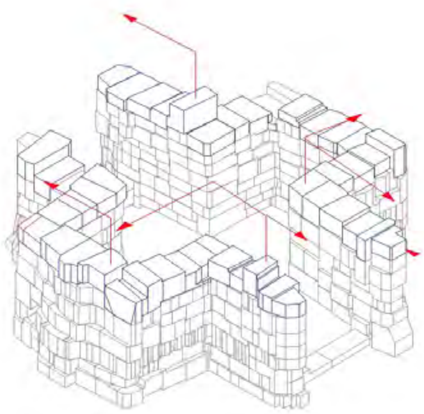
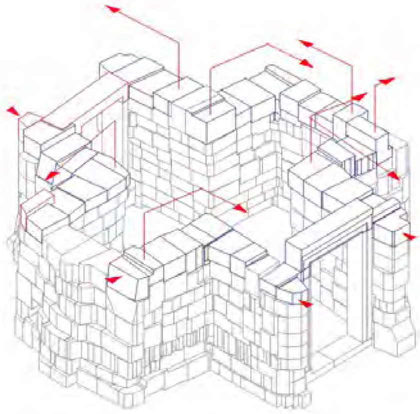


Figure 5.2.15 Assumed construction order

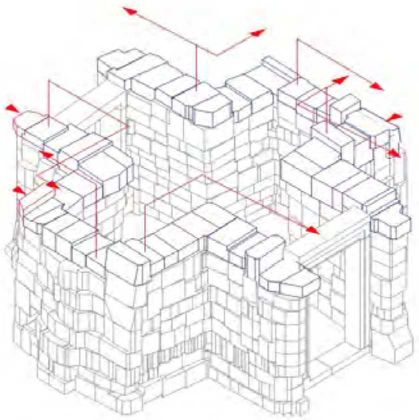
: Collapsed stones : Remained stones



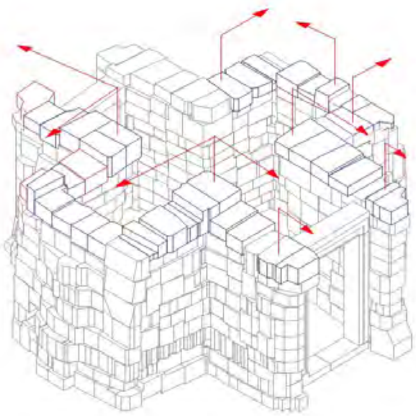
Layer 10



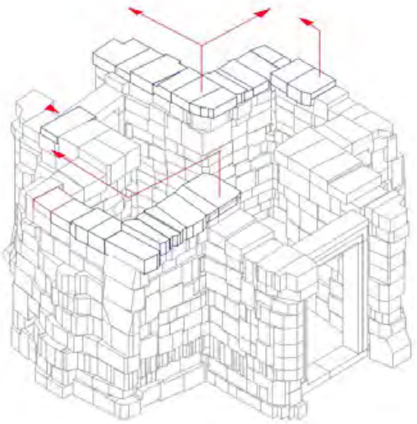
Layer 09



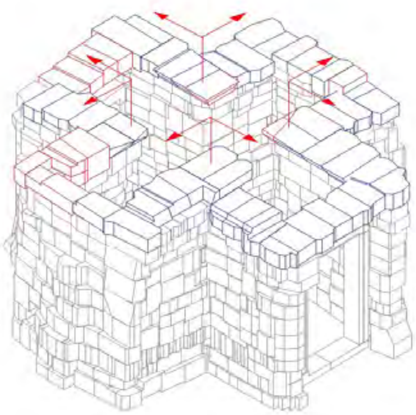
Layer 08



Layer 07



Layer 06



Layer 05

Figure 5.2.16 Assumed construction order

: Collapsed stones : Remained stones

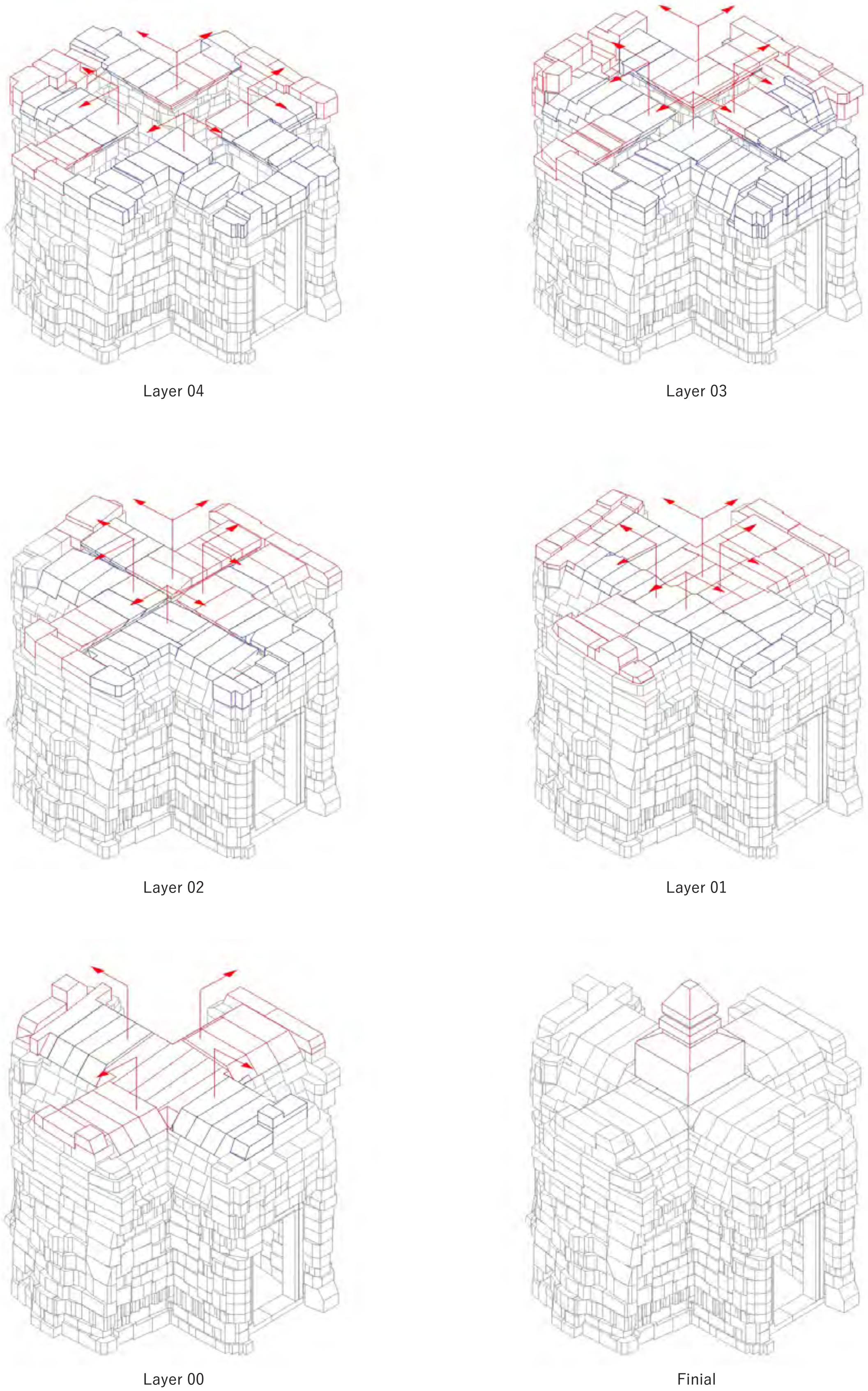


Figure 5.2.17 Assumed construction order

: Collapsed stones : Remained stones

Figure 5.2.18 Cavity on the southern inner wall of the west wing

Figure 5.2.19 Traces of holes in the wall into which a wooden-horizontal member would have been inserted at the eastern entrance

Figure 5.2.20 Colonette fragments (from the top part) found in the East Gate's surrounding area

Figure 5.2.21 Colonette fragments (from the middle part) with a flattened cross-sectional surface found in the East Gate's surrounding area

Figure 5.2.22 Bottom of the colonette that stands at the West Gate's western entrance

Figure 5.2.23 Smoothed upper surface with a hole in the bottom of the colonette that stands at the West Gate's western entrance

It is difficult to gauge from the traces how much consideration was given to the final engraving finish during the initial construction. It is generally believed that the masonry structures of Angkor were finished by engraving the surfaces after the stone construction. If this is so, it is assumed that the outer sides of the sandstone at the inner corners of the cross-shaped plane would have been planarly chipped in part. Nevertheless, not many such shapes can be found in the inner corners of the Ta Nei East Gate, with the joints tending to be placed near the inner corners (Figure 5.2.14). Possible reasons include that the stone was assembled to leave ample space and sufficient thickness for engraving, or it was shaped to some extent before the construction, and the engraved parts were slightly scraped off. Alternatively, it is possible that the portion to be cut out increased from the inner corners towards the ends, and actually, there are places where the stone depth (wall thickness) decreases towards the ends of the southern wing. Even so, it should not be assumed that these were built in a unified manner as they fit differently in the existing construction.

A cavity about the size of a human head can be found at about eye level on the southern inner wall of the western wing (Figure 5.2.18). This is also noted in the journal from when EFEO conducted its survey in 1920's (see Section 3.2), but it is unclear whether this cavity is human-made or natural.

4. Openings

The only openings of the East Gate are the east and west entrances. The windows on the walls are all false windows carved into the exterior wall. The doorways comprise colonettes, a lintel, and a door frame that supports the upper pediment. Traces of a hole in the wall into which a wooden horizontal member would have been inserted remain only on the inside of the eastern entrance, suggesting that a wooden door used to be installed there as described in Section 3.2 (Figure 5.2.19). The door frame comprised a lower horizontal member, side frames, and an upper horizontal member, with no consolidation with the walls, and standing on flat floor sandstone. The area around the opening was framed by linear engravings, although this could only be seen on the outside and not the inside. The upper and lower members of door frame on the eastern side and the upper frame on the western side each constitute a single]-shaped piece, with the lower frame at the western entrance being an exception as it comprised three pieces from the outset. The side frames were used vertically in the bedding direction, but there is a place where the stones that make up the wall extend and form part of the eastern door frame between the southeastern side frames and the upper frame.

The lintel and colonette at both entrances had collapsed and gone missing prior to restoration. Only the lintel from the western entrance and fragments of a colonette were found among the stones scattered around the building, while most of the lintel and colonette on the eastern side have not been found.

All the colonette fragments found among the scattered stones were small, and their original positions were difficult to determine, but it was possible to estimate their approximate positions so as to determine whether they belonged to a pillar top and a middle part (Figure 5.2.20). Fragments with a polished cross-section were identified for the middle part of the colonette—the colonette comprised several materials (Figure 5.2.21). In comparison with the West Gate of Ta Nei Temple, looking at the bottom part of the colonette that stands at the western entrance of the West Gate, its upper surface is likewise flat; thus, it is assumed that the colonette was made by combining several materials (Figures 5.2.22-5.2.23). Colonettes in the Angkor monuments tend to be made of one material, but there are several cases of colonettes combining several materials.

The traces on the upper surface of the sandstone floor, which is adjacent to the colonette pillar base, include a small circular mortise in the northeastern and southwestern corner where the colonette stands (Figures 5.2.24-5.2.26). The colonette was likely placed with a mortise joint at the bottom. However, in case of the East Gate, such joints differed with the places. In the southeastern corner, the colonette's pillar base is integrated with the sandstone of the pilaster base and carved out of a single material (Figure 5.2.25). In the northwestern

Figure 5.2.24 Circular mortise in the northeastern corner where the colonette stands

Figure 5.2.25 Colonette's bottom integrated with the sandstone of the pilaster base, carved from a single material, situated at the southeastern corner

Figure 5.2.26 Circular mortise for a colonette in the southwestern corner

Figure 5.2.27 Smoothed upper surface without mortise in the northwestern corner where the colonette stands

Figure 5.2.28 Tiered joints between the lintel and the upper door frame, with no mortise hole on the bottom surface of the lintel where the colonette attaches

Figure 5.2.29 Traces on the north side wall show no support for the northern edge of the eastern lintel on the wall

corner, the upper surface of the sandstone floor on which the colonette rests is flattened without any trace of a tenon or indentation (Figure 5.2.27).

None of the colonette fragments scattered among the stones exhibit a tenon or such on the upper surface of the pillar top, while none of the bottom surface of the lintels that fit on top have any hole for a tenon to fit in (Figure 5.2.28). This indicates that the colonettes and lintels were simply placed over one another without being integrated.

The lintels were not all placed in the same manner, as well. The lintel at the western entrance has the southern end attached without anything holding to the wall. The northern end scrapes its upper end and integrates with the attached side wall by placing the protruding stone from the wall above it. The eastern lintel remains missing, but traces left on the adjacent wall suggest that the southern end extended to about half the sandstone that made up the pilaster and secured it by incorporation into the side wall's masonry, while the northern end left only a trace of attachment on the side wall, suggesting that there was nothing to support the lintel with the wall (Figure 5.2.29). The back of the lintel would be given a tiered shape so that it would fit and be put together with the upper door frame, similarly given a tiered appearance (Figure 5.2.28). The upper surface of the upper door frame and lintel were aligned, and traces of them being fastened to each other with H-shaped clamps have been found (Figure 5.2.30). The H-shaped clamps are no longer there; only the clamp holes remain atop the stone. Considering the extent of damage at the end of the clamp holes, it would seem that the stone collapsed before the iron clamps rusted away, causing damage around the clamp holes (Figure 5.2.31). In the future, matching with these H-shaped clamp holes may provide valuable clues to identifying the missing eastern lintel.

To summarise the placement of the openings described above, colonettes comprising with several members were stacked from the floor level and lintels mounted thereupon. The lintels partly worked into the walls, and their backsides were fastened to the opening frames and integrated with clamps so that the load from above was distributed among the colonettes, walls, and opening frames. However, there is a seeming lack of uniformity vis-à-vis how the pieces are attached, as described above.

5. Pediments

The east and west pediments were supported by lintels, colonettes, door frames, and pilasters curved out from the walls. The east and west pediments on top of the openings and the north and south pediments on top of the wall had stones stacked in different directions (Figure 5.2.32). With the east and west pediments, the sandstone ends face outwards to straddle the lintels and opening frames, with only the upper double flame-shaped back portions being stacked longitudinally. You can view this as a structure where the stones constituting the pediments protrude from the door frames like cantilevers so that the lintels and colonette below bear as little load from above as possible. The north and south pediments have a single flame-shape and are thin overall. Thus, the stones in the longitudinal direction of these parts are stacked outwards.

6. Roof

The roof is made of long sandstone blocks with visible edges, gradually extending inwards on the inside to create a corbel arch. At the central part of the cross-shaped plane, a cross-vault is formed. At the inner corners of the roof, sandstone members were alternatingly stacked layer by layer, except a few layers. The roofing is attached differently from the wall sandstone in that the blocks link with each other via sloped step-shaped joints, presumably, to prevent water penetration (Figure 5.2.33). The appearance of these stone joints suggests that they were stacked from the centre of the cross-shaped plane towards the ends of the four wings.

At the top of the cross-vault, where the corbel stones touch each other, a palm-sized hole was artificially

Figure 5.2.30 Upper surface of the lintel and the door flame, fastened using H-shaped clamps

Figure 5.2.31 Traces of H-shaped clamps on the lintel and the upper door flame

Figure 5.2.32 Difference in the construction method between the northern and eastern pediments

Figure 5.2.33 Sloped step-shaped roof stone joints

Figure 5.2.34 Roof stone layout on layer 01, with a palm-sized hole artificially drilled into the northeastern roof stone's upper surface

Figure 5.2.35 Flattened upper surface of the top lotus-shaped pedestal

drilled into the upper surface of the northeastern stone, closest to the centre on the plane (Figure 5.2.34). Some kind of artefact was perhaps inserted there.

At the top of the roof of the wing, the centre of the upper surface is slightly recessed in a groove to hold ridge decorations, which combine two or three pieces per wing. The ridge decorations are corrugated. The images, assumably related to Buddhism, of the recesses on both sides are cut with chisels. It is only at the centre of the top level of the cross-shaped roof that a long block with a flat top surface has been placed in the north-south direction to stabilise the corbel arch structure and hold the finial base.

7. Finial

Going from the bottom, the finial comprises a flat square base, an inverted lotus, and a two-tiered lotus-shaped pedestal. Three layers of stones are stacked with the longitudinal direction facing outwards at the centre of the roof, forming a 1.9-by-1.9 m square base. On top of that sits a lotus-shaped pedestal with an inverted lotus design. The inverted lotus is made more or less by combining a piece of sandstone like a cross-section of orange, but some placements are irregular as well. No trace of these stones having been held together by clamps was found. On the top surface of the inverted lotus sits a two-tiered structure of a bigger and smaller lotus. The upper surface of the top lotus-shaped pedestal is flattened, so there likely used to be something on top of it, but no relics of the sort have been found among the scattered stones (Figure 5.2.35). As no other examples similar to the finial of the East Gate can be observed, it is difficult to guess the shape of the missing part.

5.2.2. Trace of the original ground surface at the initial construction

The appearance of the finish of the exterior sandstone wall around the foundation suggests that it may be possible to estimate what the ground surface was like when the East Gate was first built. On the eastern side, engravings were made on the exterior sandstone down to two rows below the floor, whereas on the western side, engravings were only made down to one row below the floor level, with the sandstone below lacking finish. As the engravings would have been made on visible surface and exposed above ground, it can be inferred that the height of the ground surface initially differed between the eastern and western sides so that the western ground surface was 0.4–0.5 m higher than that of the eastern side (Figures 5.2.36 - 5.2.37). Simultaneously, the level of the lower edge of the base laterite at the bottom of the foundation would have been more or less the same on the two sides.

Regarding initial height differences in the ground around the East Gate, all the ground within the Outermost Enclosure might have been higher than outside, or the ground might have been raised only around the central axis along the approach. Excavations were conducted near the northeastern side of the Outermost

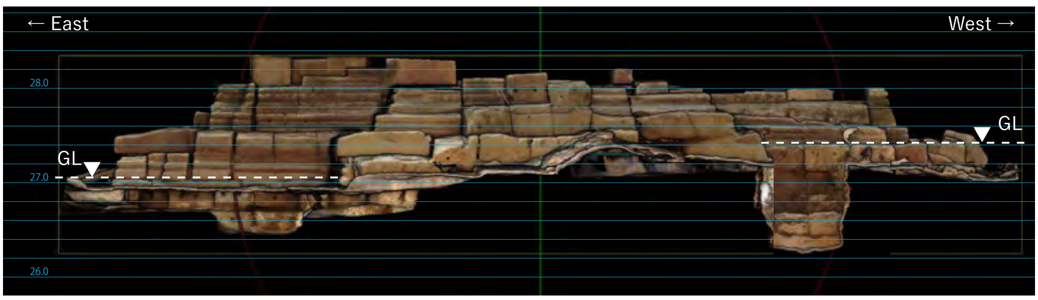


Figure 5.2.36　Base structure's north elevation created from 3D-laser scanning model, indicating the difference of the original ground level between the eastern and western sides of the East Gate

Enclosure, uncovering three trenches. However, traces of the original ground surface were not clear between the inside and outside of the Outermost Enclosure, making it seem that the height differed based on the location.

A series of surveys that included an excavation of the Terrace on the Embankment (Abe, Kansha, An, San & Sea: 2019) revealed that the height difference from the highest point of the laterite on the embankment terrace to the ground surface on the eastern side of the East Gate was approximately 4.5 m when examining the height relationships among the structures while gently descending the approach from the Terrace on the Embankment to reach the East Gate and then the Cruciform Terrace in front of Central Complex.

5.2.3. Connections among the East Gate, the Outermost Enclosure, and the causeway

(1) Connections between the base structure of the East Gate and Outermost Enclosure

Little remains of the Outermost Enclosure, except for part of the foundation. Nevertheless, there are traces of Outermost Enclosure having been attached to both sides of the East and West Gates (northern and southern sides), assumed to have been about 3 m high (Figure 5.2.38).

The connections between the East Gate and Outermost Enclosure were checked by the dismantling survey, which found that part of the bottom of the remaining Outermost Enclosure's base had come under the exterior sandstone of the East Gate (Figure 5.2.39). It was confirmed that the exterior sandstone of the East Gate's base structure had been cut and processed to accommodate the base laterite of the Outermost Enclosure (Figure 5.2.40). As the East Gate and the Outermost Enclosure's base structure are intertwined, it is assumed that the East Gate and Outermost Enclosure were built simultaneously. Nonetheless, the possibility that the Outermost Enclosure existed first and that part of those walls were demolished later to build the East Gate cannot be ruled out completely.

(2) Connections between the East Gate and the causeway on the west side of the gate

Currently, there is no structure along the approach that connects the East Gate with the Cruciform Terrace on the east side of the Central Complex and the approach area between the East Gate and the terrace is covered with topsoil, but between the West Gate and Cruciform Terrace on the west side of the Central Complex, a causeway paved with laterite remains. It would have been unnatural for there to have been an approach on the western side, which is the rear, and none on the eastern side, which is the front. Therefore, there might have been some paved structure along the approach connecting the East Gate and Cruciform Terrace in front of the Central Complex at some point in the past.

A possible candidate for this is the laterite block placed in the southwestern outer corner of the East Gate's western entrance (Figure 5.2.41). The upper surface of the sandstone directly beneath this laterite shows traces of previously having been underneath a stone of a different size. This leads us to assume that the original stone was moved at some point and that this other laterite was inserted there in its place. No corresponding stone can be found in the northwestern corner, so the details are unknown. There is another place in the southwestern corner where laterite blocks have been inserted irregularly into the exterior sandstone, which is the visible part of the base structure (Figure 5.2.42). All parts of the East Gate's exterior design comprise sandstone, with the two abovementioned stones appearing in this design as glaring exceptions. It is conceivable that the laterite in the southwestern outer corner may have been part of an approach that was laid at some point in time after the construction of the East Gate. Nevertheless, it is equally possible that it was accidentally placed there at a later

Figure 5.2.37 Engravings on the exterior sandstones, indicating the original ground level

Figure 5.2.38 Traces of Outermost Enclosure attached to both sides of the East Gate

Figure 5.2.39 Part of the bottom of the remaining Outermost Enclosure' base under the East Gate's exterior sandstone

Figure 5.2.40 North side of the exterior sandstone of the East Gate's base structure, cut and processed to accommodate the Outermost Enclosure' base laterite

Figure 5.2.41 Laterite block irregularly placed at the southwestern outer corner of the East Gate's western entrance

Figure 5.2.42 Laterite block irregularly inserted at the southwestern outer corner of the East Gate's south wing

time, as a laterite has been used unnaturally in another place as well. Excavations near the Cruciform Terrace have revealed traces of modifications to the eastern end of the terrace (Abe, Kansha, Sea & Sitha, 2020: 35-37), which may have been related to the construction of an approach connecting the East Gate and Cruciform Terrace.

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Chapter 6

Structural Analysis

6.1. Geotechnical Investigation

KUWANO Reiko, OTSUBO Masahide

6.1.1. Geotechnical investigation on the base structure

(1) Dynamic cone penetration test

After the wall dismantlement was completed, the necessity of the dismantlement of base structure was discussed. At this stage, it was agreed between APSARA and TOBUNKEN that the implementation methods should be decided based on the test outcomes on strength of the base structure. To understand the structural strength of the existing base structure, the dynamic cone penetration test (DCPT) was conducted at 6 points (P1-P6) in December 2019, and at 5 points (P7-P11) in March 2020.

The DCPT measures the penetration resistance of a rod with a cone-shaped head by a given impact created by a 5-kg falling weight from a height of 50 cm. The number of hits required for a 10-cm rod penetration was recorded as values of Nd. The DCPT was conducted as explained below.

Before conducting DCPT, two deep soundings measuring 1 m by 1 m were opened on the southeastern and northwestern corners of the East Gate as described in Section 5.1 (Figure 6.1.1). As a result, the sand foundation, on which the East Gate was constructed, was revealed 80 cm below the original ground surface of the Angkor Period. To examine the structural strength of the sand foundation, the DCPT was conducted at two points: Points 1 and 2 (Figure 6.1.2, upper left).

Furthermore, to investigate the inside of the base structure, parts of the floor pavement of the East Gate were removed. As a result, a course of laterite blocks was discovered beneath the floor pavement. Because the

Figure 6.1.1 Locations where the DCPTs were conducted

Figure 6.1.2 Implementation of the DCPT

laterite blocks were heavily weathered, and therefore fragile and difficult to remove, they were bored at three points to examine them further as well as the area below them. The examination showed that the space between the laterite blocks and sand foundation is probably filled with compacted soils. To examine the strength of this soil filling, the DCPT was undertaken: Points 3, 4, and 6 (Figure 6.1.2, upper right), and to examine the strength of the weathered laterite blocks and soil filing below them, DCPT was also undertaken at Point 5. Furthermore, to examine the strength of the soil filling below the structure wall and other points, DCPT was conducted at Point 7, 8, 9, 10, and 11.

The Nd values of all the points are presented in Figure 6.1.3. At Points 1 and 2, the Nd values seem to steadily increase when the increasing depth. At Points 3-6, the Nd values of the soil filling were approximately 10–20 with some fluctuations. Further, the Nd values of the weathered laterite blocks were calculated as 30–60.

The following relationships were proposed for the conversion of Nd values to N values of the standard penetration test (SPT):

Okubo et al. (1971) : N = (1/3~1) Nd (1)

Okada et al. (1992) : for Nd ≥ 4,

N = 0.7 + 0.30・Nd (gravel) (2-1)

N = 1.1 + 0.30・Nd (sand) (2-2)

N = 1.7 + 0.34・Nd (clay) (2-3)

Considering that the soil filling inside the base structure is sandy, SPT-N values were estimated using equation (2-2) (Figure 6.1.3); these are almost equivalent to the minimum values estimated from equation (1). The estimated SPT-N values of the soil filling layer were determined to range between approximately 5 and 10.

The outcomes of the DCPT were represented that the test points below the wall structure have generally stronger values than that of in the central area of the building. It is considered that the difference in the strength might be related to two main factors: The first reason would be related to the fact that the static load of the wall structure may have resulted in a more compacted soil and increased the strength. Another reason for the difference in the results would be related to the difference in the water content of the infill soil at the time of the tests. The first test was conducted in December, when the ground was more wet than that of in March, when the second test was conducted. It is assumed that the difference in the water content may also impact the test results.

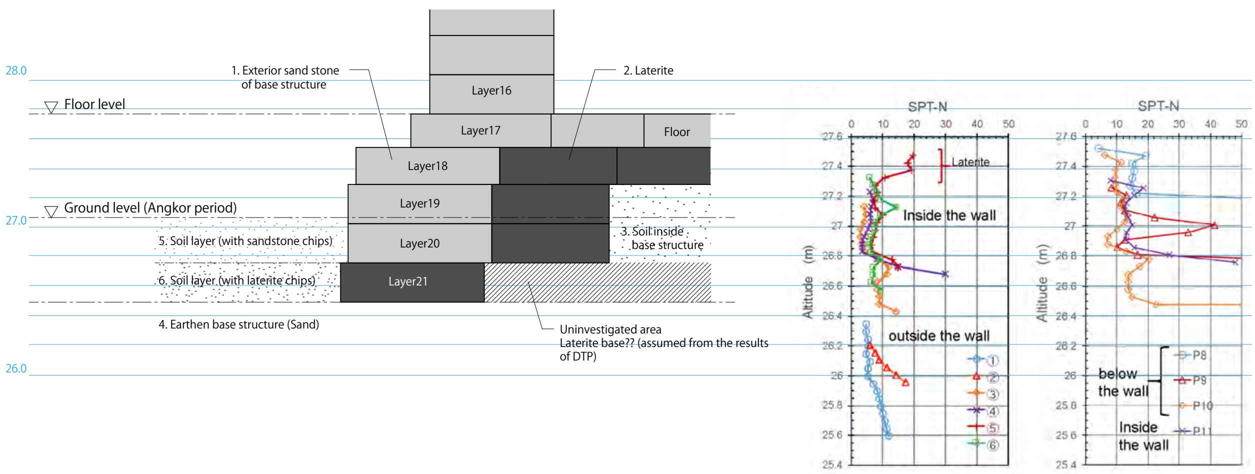


Figure 6.1.3 Estimated SPT-N values

(2) Soil sampling

In addition to DCPT, a soil sampling was carried out in March 2020. Located approximately 45 cm far from the western side of the Point 11 (Figure 6.1.4), the sampling was conducted in the area where the laterite sample was taken. For this purpose, a sampler with a diameter of 2 cm was attached to the tip of the hand auger, and was pulled out every 10 cm from the upper surface. The soil in the sampler was collected for the portions of every 5 cm. The resistance of the soil remarkably increased when the depth has reached to 60 cm and it became very difficult to drill. Therefore, the boring was finished when the depth has reached to 70 cm in total. The soil above this interface was a soil layer which contains greyish brown sand, whereas a very fine, orange-coloured homogeneous silt was found below it. Investigations on the property of the soil samples was conducted and described in Section 7.2.

6.1.2. Material strength

To understand the material strengths and the properties, P wave measurements, soil hardness tests and unconfined compression tests were conducted. For this purpose, three kinds of specimen, namely old laterite, new laterite and new lime mortar, (which is made from the mixture of clay, laterite powder, sand, and slaked lime, and used when replacing the deteriorated or decayed stones inside the base platform during the rebuilding process) were used with a dimension of 50 mm by 50 mm by 100 mm (Figure 6.1.5).

The results of the unconfined compression test and P wave measurement are shown in Figures 6.1.6 and 6.1.8. They indicated that the old laterite has 10 % smaller unconfined compression strength, whereas it has 40 % greater P wave velocity. Peak stress state was reached at 0.5 to 1.0 % of axial strain. Unconfined compression strengths of old laterite specimens were scattered although all the specimens were taken from the same material. It seems that the local strength of weathered laterite becomes more non-uniform. Origin of old and new laterite seem to be different, which should cause the difference of physical and mechanical properties. Therefore the difference of old/new specimens may not be directly due to the weathering effect. On the other hand, in terms of the properties of the lime mortar, the results showed that the structure is uniformly layered and it has stable properties. The surface hardness was also measured using a Yamanaka-type soil hardness tester (Figure 6.1.7).

To sum up, it was confirmed that there was no significant difference in the strength of the old and the new laterite blocks. It was also understood that the dry density and the P wave velocity of lime mortar was larger than expected.

Figure 6.1.4 Implementation of the DCPT and soil sampling

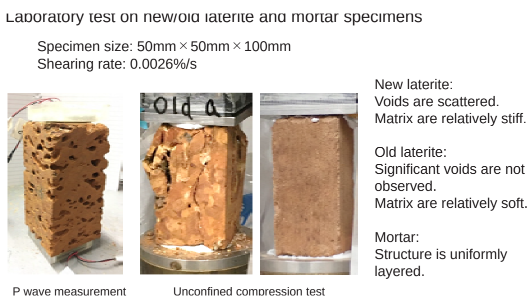


Figure 6.1.5 Specimens

material	wet density [g/cm³]	water content [%]	dry density [g/cm³]	P wave velocity [m/s]	unconfined compression strength [MPa]	photos: before test / at peak stress / after test / after test
New Laterite	1.99	3.6	1.92	1314	ave. 3.81 3.86, 3.79 3.78. 3.83	
Old Laterite	2.34	2.8	2.28	1843	ave. 3.40 3.63, 2.23 3.27, 4.45	
Mortar	2.04	6.2	1.92	990	ave. 0.55 0.51, 0.58, 0.56	

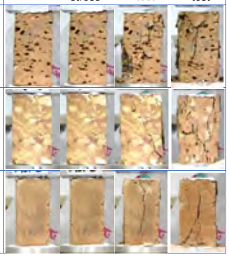
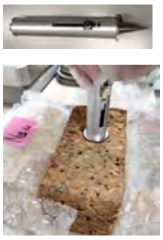


Figure 6.1.6　Results of the unconfined compression test and P wave measurement

Soil hardness tester, Yamanaka



Surface hardness - averaged values for 3 – 5 tests

Material	Mineral type	MPa
New laterite	Normal	223.0
	White	82.9
Old laterite	Normal	462.0
	White	21.0
	Grey	8.8
Mortar	Normal	22.0

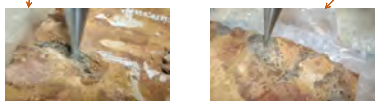


Figure 6.1.7　Surface hardness of the specimens

New Laterite
q_{max} = 3.81 MPa
(3.86, 3.79, 3.78, 3.83)

P-wave velocity : 1314 m/s

Old Laterite
q_{max} = 3.40 MPa
(3.63, 2.23, 3.27, 4.45)

P-wave velocity : 1843 m/s

Mortar
q_{max} = 0.55 MPa
(0.51, 0.58, 0.56)

P-wave velocity : 990 m/s

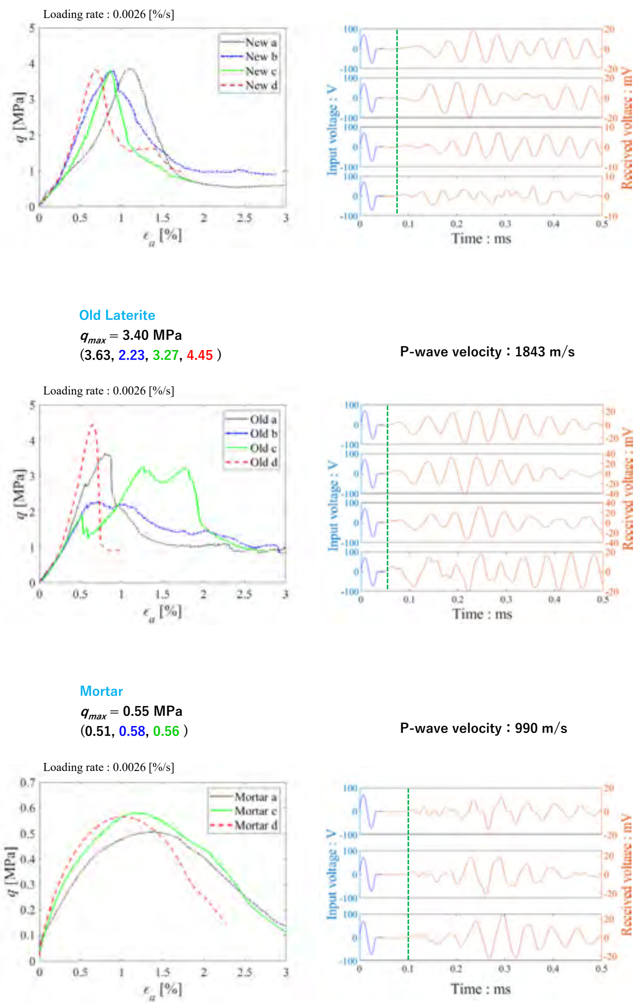


Figure 6.1.8
Outcomes of P-wave velocity test
(A: Old laterite, B: New laterite, C: Mortar)

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6.2. Structural Analysis

KOSHIHARA Mikio

(1) Location

Cambodia has historically been an area with exceedingly few earthquakes. It is categorised among states with the weakest seismic effects on the UN OCHA's Earthquake Risk Map. A map of tropical monsoon occurrences over the past five decades shows that strong tropical monsoons hit the Cambodian inland, where Siem Reap is located, only rarely. Starting from the surface, the basic geological structure of the Siem Reap area comprises alluvial sedimentary layers of silty coarse-grained sand, clay sand (rock) with silt (rock) and coarse-grained groundmass, eluvial sedimentary layers of gravel sand, Pliocene sedimentary layers of sandy clay rocks, and bedrock. Precipitation volumes vary significantly between the rainy and dry seasons, with the groundwater level fluctuating considerably from one season to another.

(2) Outline of the building structure

The building is a masonry structure comprising sandstone and laterite blocks. The plane is approximately 6 m by 6 m, and the total height (from the ground to the top) is about 7 m. No joint filler such as mortar was used between the masonry blocks. The base comprises sandstone placed on the exterior of a cross-shaped plane, with laterite blocks lining the interior and compacted soil stabilising in the space in between. The walls are made of small piles of sandstone blocks, but the stacking methods vary as described in Section 5.2. The roof is a corbel arch, and the central part of the cross-shaped plane comprises a cross vault. A finial can be found at the roof apex.

(3) Building weight

To investigate whether the existing base structure can support the superstructure adequately, the building weight was calculated for the walls and roof above the base structure (=floor level). The following relative density data were used in the calculations.

	Weight (t)
Finial	14.6
Roof	55.8
Pediment	36.0
Wall+Floor	145.6

Sandstone P= 2.69 (t/ m³)

Building weight: 252 tf

(4) Factor analysis on the basement

As earthquakes are exceedingly rare in Cambodia, the effects of seismic forces were not considered this time.

Compressive strength of the base structure (see Section 6.1)

Material	Compressive strength
Laterite (New)	3.81 Mpa
Laterite (Old)	3.40 Mpa (minimum 2.23 Mpa)
Mortar (Sand, Laterite, Cray, Lime)	0.55 Mpa
Base structure (Compacted soil)	0.3 Mpa = 10(t/ m²) × 3

*Failure strain 1 % *1 Mpa=10 kg/m^2=100 t/m^2

3 Mpa = 30 (kg/m^2) = 300 (t/m^2) × 1/3=100 (t/m^2)

Pmax= 0.3 MPa　 estimated from N value

0.2-0.3 Mpa = 7 (t/m^2) × 3　10 t/m^2 (0.3 MPa)

The results of the material testing reveal that the compressive strength values of the new laterite blocks, existing laterite blocks, and lime mortar added to adjust gaps were 3.81 MPa, 3.40 MPa, and 0.55 MPa, respectively. The materials provided sufficiently strong components to support the superstructure.

The results of the simple dynamic cone penetration test (DCPT) of the strength of the base structure's compacted soil layers show that the N value within the compacted soil layers is less than 10 while being around 10 directly under the walls where most of the load is located. To support the upper load, a ground bearing load N value of 10 is sufficient in the ground extending downwards at an angle of 45 degrees from the wall width. The base structure's compacted soil layers portion is deemed to be narrowly strong to support the superstructure. The base structure does not seem to have any considerable uneven parts, likely because it has been compacted by long-term consolidation. Dismantling the base structure risks loosening the ground that has been compacted over the years, causing an outflow of inner soil and destabilising the building's structure as a whole. Thus, it is concluded that the existing base structure is sufficiently strong to support the superstructure. This makes it desirable to rebuild the superstructure without dismantling base structure.

(5) Approach to reinforce the superstructure

1. Approach to reinforce the roof

The load on the roof as a whole may be calculated as follows.

Finial　　　　　　w_1= 5.42 ㎥ × ρ = 14.6 tf

Roof (3 Layers)　　w_2=20.74 ㎥ × ρ = 55.8 tf

Pediment　　　　　w_3=13.39 ㎥ × ρ = 36.0 tf

The sandstone's relative density is　ρ = 2.69

The total roof weight is　　　Wr = w_1 + w_2 = 70.4 tf

If we assume that it is supported by a corbel arch comprising four rows of masonry, the load supported by the protruding portion will be as follows.

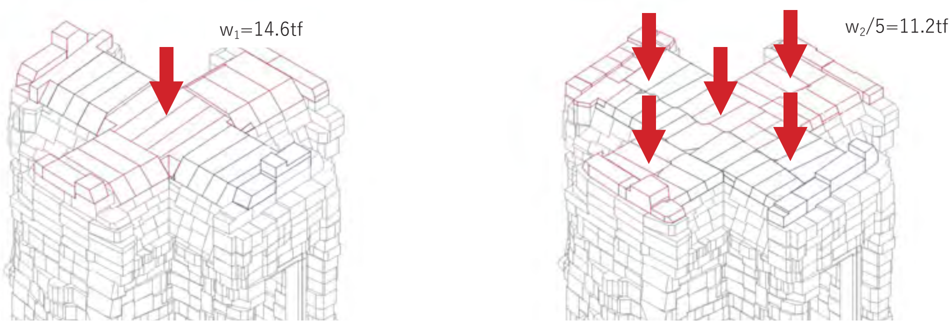

Figure 6.2.1　Load on the roof

$w_1 + w_2 / 5 = 14.6 + 55.8 / 5 = 25.8$ tf

As there will be 4 rows of corbel, the vertical load borne by each corbel arch will be as follows:
25.8 tf / 4 = 6.5 tf

(a) Reinforcement method

As shown in the figure, a tensile force is generated in the lower part (Layer 1) of the corbel arch, but as the stones are split, integration is possible by inserting a tension member, suppressing the thrust, and keeping down the exertion of force to the parts jutting out of the corbel arch, a structurally weak point.

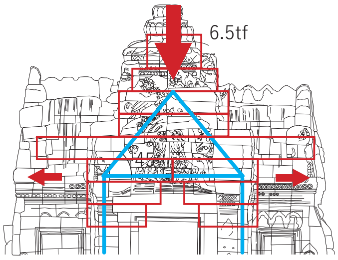

Figure 6.2.2 Diagram of the force in the corbel arch

Tensile force borne by the tension member 6.5 / tan 45° / 2 = 3.3 tf
Required cross-section of the tension member $a_t = 3.3/1.6 = 2.0$ ㎠
Stainless steel bar SUS304 F = 2.4 tf/cm^2
2 × 12 ϕ = 2.2
1 × 16 ϕ = 2.0
However, 12 ϕ a = 1.13 ㎠ ; 16 ϕ a = 2.00 ㎠

Each corbel requires two stainless steel bars at 12 ϕ or one at 16 ϕ . These may be installed by penetration inside the stone or along the upper and lower surfaces or sides of the roof stone. It is necessary to repair and reinforce broken stones so that they can transmit at least compressive and shear force.

2. Walls

If the aforementioned thrust is resisted by the lower walls, the shear force Q and the moment M applied to the walls owing to the load from the roof will be as follows:

Q = 3.3 t
M = 3.3 × 3.6 = 11.88 tm (wall height of 3.6 m)
M = 3.3 × 2.8 = 9.24 tm (wall height of 2.8 m)

If we assume a stone cross-section of B × D = 25 × 50 cm, the amount of rebar required for the bending moment will be as follows:

With a wall height of 3.6 m $a_t = 11.88 \times 100 / 40 / 1.6 = 18.56$ ㎠
With a wall height of 2.8m $a_t = 9.24 \times 100 / 40 / 1.6 = 14.44$ ㎠

If so, the walls' out-of-plane bending resistance is insufficient.

If shear force is transmitted to an orthogonal wall, the cross-sectional area of the dowels needed to bear the shear force will be as follows:

$a_s = 3.3 / 0.9 = 3.66$ cm²

Stainless steel bar SUS304 F = 2.4

4-12 ϕ　4 x 1.13 = 4.52

2-16 ϕ　2 x 2.00 = 4.00

Each stone will require four stainless steel dowels at 12 ϕ or two at 16 ϕ. If we also consider the effects of the rebar reinforcement, it is possible to reduce the number of rebars to avoid affecting the stone adversely.

3. Pediments

The pediments are exposed to forces that push them out of the plane; thus, they must be tied to a principal part of the building. The load of each pediment, assuming 4 m in width, 3.6 m in height, and 30 cm in average thickness and a horizontal acceleration of 1 G to prevent falling, is as follows:

Weight　$W = 4.0 \times 3.6 / 2 \times 0.3 \times 2.69 = 5.8$ tf

Tensile force in case of toppling　$N = 5.8$ tf

The required cross-sectional area of the clamps (stainless steel) is

$a_t = 5.8 / 1.6 = 3.6$ cm²

Stainless steel bar SUS304 F = 2.4

4-12 ϕ　4 x 1.13 = 4.52

Four stainless steel bars 12 ϕ would be necessary.

These structural calculations only consider joining from the reinforcing components, disregarding friction. The reinforcement materials can be reduced if friction and stops between stones are considered.

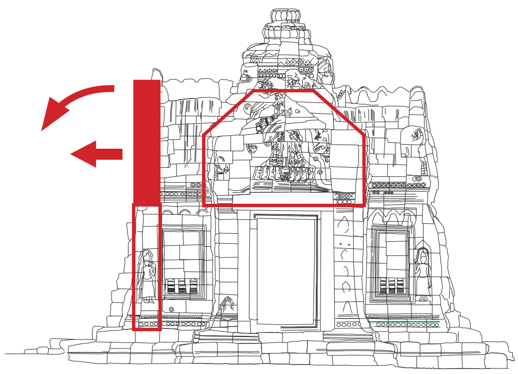

Figure 6.2.3　Diagram of the force in the pediments

(6) Concluding remarks

As the building is located in an area where earthquakes are uncommon, seismic forces have not been considered. Thus, only vertical loads have been included in the structural calculations. First, to determine the extent of the base structure that must be dismantled, material test and DCPT were conducted on the base structure. The results show that the existing base structure is sufficiently strong to support the superstructure. Visually, as not much considerable unevenness or outflow of inner soil was observed in general, it was assumed that the base structure was compacted by long-term consolidation. Although the base structure has sustained little damage, the roof and pediment materials had collapsed before dismantling, lying scattered around the building, and the walls were externally deformed. The likely causes were structural weaknesses that go back to when it was first constructed, such as the relatively small size of individual material units and numerous places where vertical joints pass through.

We considered ways to reinforce the building to at least compensate for these structural weaknesses. The roof will comprise a cross vault with a central corbel arch that bears the greatest load, with a stainless steel bar to be inserted at the bottom of the arch to reduce the horizontal force caused by thrust. The stone slippage caused by the shear force and moment from the upper load will be suppressed by inserting dowels. By stabilising the central parts, we expect that the out-of-plane protrusion towards the periphery can be kept down. The pediments will be tied to a principal part of the building to prevent them from being pushed out of the plane. The materials and quantities thereof required for these reinforcements have been estimated.

Nonetheless, the actual implementation methods of structural reinforcement was decided making observations on-site on how the stones fit together when the reinforcement materials are inserted.

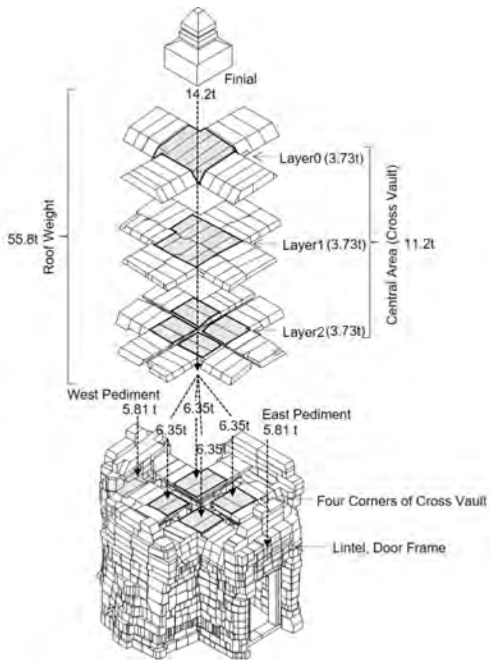

Figure 6.2.4 Schematic diagram of the parts where static load is concentrated

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Chapter 7

Material Analysis

7.1. Analytical Results for the White Materials Adhering to Stones

INUZUKA Masahide

(1) Introduction

During the dismantling of the East Gate, it was found that white material adhered to the surface of the dismantled stones. Although all white materials were found on the joint surfaces between stones, it has not been reported thus far that joint materials were used for buildings made of sandstones with masonry structures in the Angkor period. To examine the chemical composition of the white materials, samples extracted from the dismantled stones were investigated using microscopic observation, X-ray fluorescence analysis (XRF), and X-ray diffraction analysis (XRD). The results of the analysis are presented as followings.

(2) Samples

The analyses were conducted on the following five samples: They were white materials extracted from the joint surfaces of sandstone walls. After cleaning the mud, the white material was extracted using a metal spatula. The white materials in powder form were sorted according to the sandstones from which the materials were extracted, and each was placed in a separate zipper bag. The samples were named after the stone numbers labeled during the dismantling as “NB 14/7 B,” “NB16/11,” “NB 7/13,” “SB 15/4 (more)” and “SB 15/4 (less).” The samples “SB 15/4” were extracted twice separately from the same stone, and are distinguished here; according to the mounds of materials, they were named “SB 15/4 (more)” and “SB 15/4 (less)” in this report.

(3) Analysis methods

The five samples described above were investigated using microscopy, XRF, and XRD at the Tokyo National Research Institute for Cultural Properties. These analyses were conducted under the following conditions:

1. Microscopic observation

Microscopic observations were performed using a digital microscope, VHX-100 (Keyence Corporation) at 100 times magnification.

2. XRF

XRF was conducted using M4 TORNADO (Bruker Corporation) under atmospheric conditions. The anode material used in the X-ray tube was rhodium (Rh). The tube voltage and current were 50 kV and 200 μA, respectively. The spot size of the incident X-ray was 20 μm.

3. XRD

XRD was conducted using X'Pert PRO (Spectris Co., Ltd.) under atmospheric conditions. The anode material used in the X-ray tube was copper (Cu). The tube voltage and current were 40 kV and 10 mA, respectively. The measured 2 θ range was from 5to 70°. The step size of θ was 0.0020°.

(4) Results

1. NB 14/7 B

Figure 7.1.1 presents the microscopic image of NB 14/7 B. Most part of the sample was composed of fine white particles whose size was smaller than 10 µm. Moreover, tiny amounts of black and brown particles were observed in addition to white particles.

As presented in Figure 7.1.1, NB 14/7 B was almost uniform. XRF was performed at three points on the sample (Figures 7.1.2–7.1.4). The spectra obtained at these points were similar, and primarily Ca, Fe, and Si were detected.

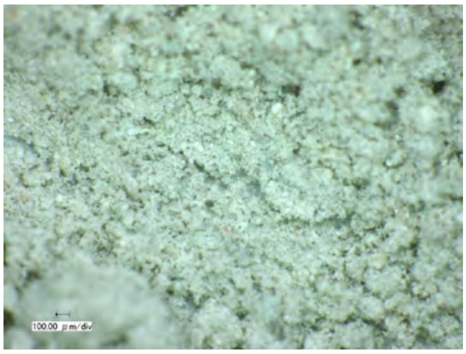


Figure 7.1.1　Microscopic image of NB 14/7 B

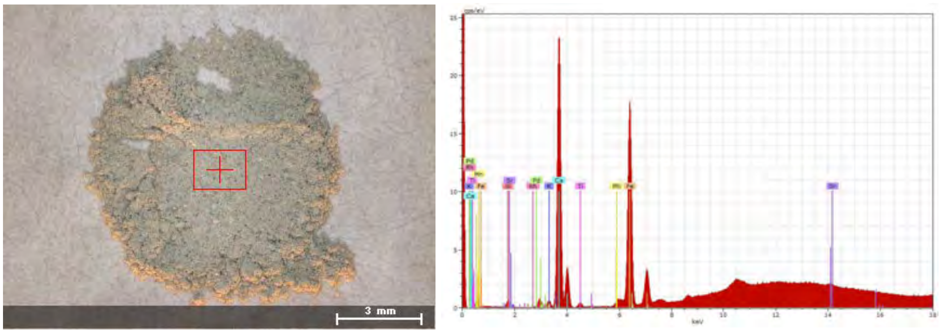


Figure 7.1.2　XRF spectrum of NB 14/7 B　①

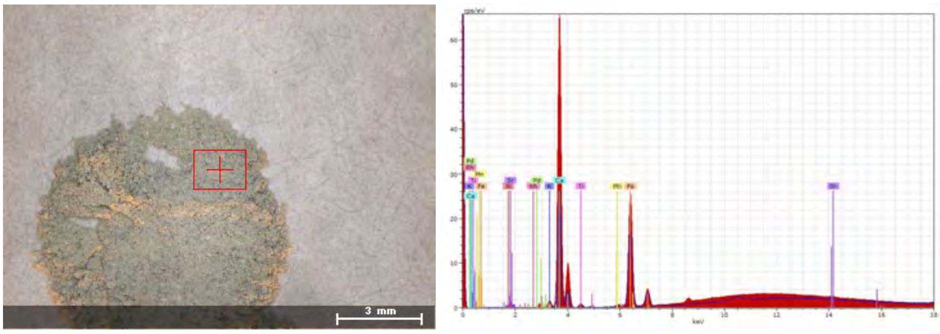


Figure 7.1.3　XRF spectrum of NB 14/7 B　②

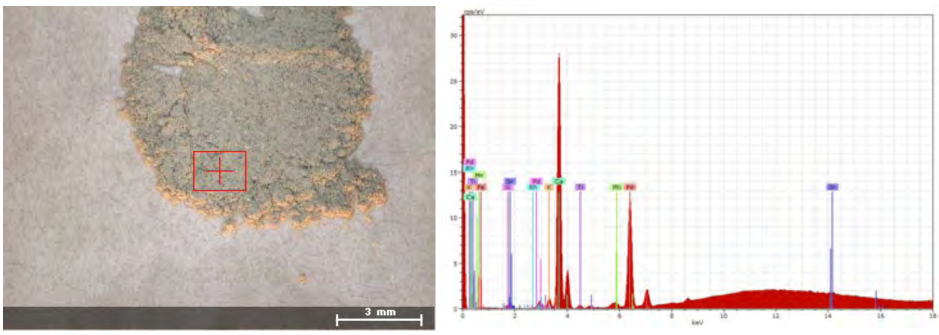


Figure 7.1.4　XRF spectrum of NB 14/7 B　③

Figure 7.1.5 presents the result of XRD. Calcite and quartz were identified by matching the reference data. The patterns of the other peaks appeared to agree with the reference data for oligoclase.

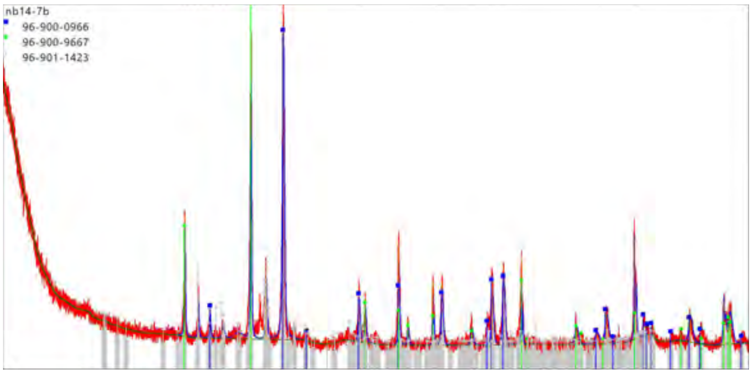


Figure 7.1.5 XRD result of NB 14/7 B. Blue, green, and gray symbols represent calcite, quartz, and oligoclase, respectively

2. NB 16/11

Figures 7.1.6–7.1.8 present the microscopic images of NB 16/11. This sample comprised particles with various colours and typical size of these particles was 100 μm (Figure 7.1.6). Some brown particles to which the white material appears to be adhered are presented in Figure 7.1.7. A dead bug is presented in Figure 7.1.8.

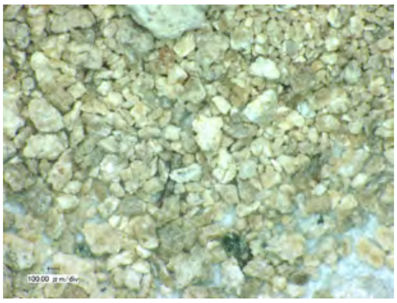


Figure 7.1.6 Microscopic image of NB 16/11 ①

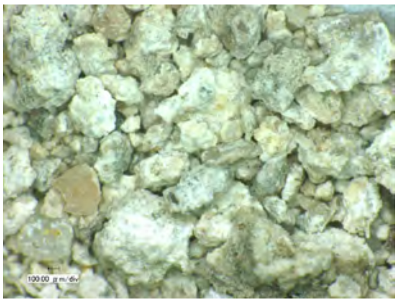


Figure 7.1.7 Microscopic image of NB 16/11 ②

Figure 7.1.8 Microscopic image of NB 16/11 ③

From the above microscopic images, it can be observed that NB 16/11 was composed of particles of various colours and sizes. XRF was performed at seven points, and the measurement results are summarised in Table 7.1.1 and the obtained spectra are presented in Figures 7.1.9–7.1.15. The intensity of the signals owing to Ca was high at the measurement points demonstrating white and gray colours. In addition to Ca, the signal intensities of Fe and Si were high, and small signals of K and Sr were detected at most measurement points. The Zr signal was high from point ① . The results of microscopic observations and XRF measurements suggest that NB 16/11 was a mixture of mortar and soil.

Table 7.1.1 Summary of XRF measurements

Mesurement point	Colour	Detected elements	
①	orange, gray	Fe, Ca, Si, Zr	Zr was detected.
②	gray	Ca, Fe, Si	
③	white	Ca, Fe, Si	
④	red, black	Ca, Fe, Si	
⑤	orange	Ca, Fe, Si	Signal intensity is low.
⑥	orange, red	Si, Ca, Cr, Ni, Fe	Signal intensity is low. Can and Ni were detected.
⑦	white	Ca, Si, Fe	

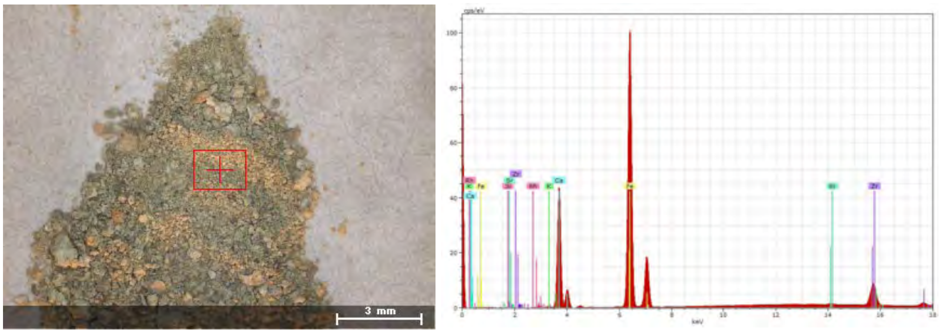


Figure 7.1.9 XRF spectrum of NB 16/11 ①

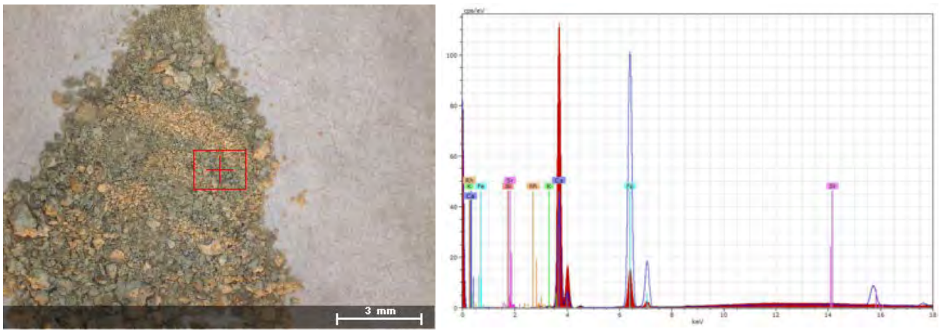


Figure 7.1.10 XRF spectrum of NB 16/11 ②

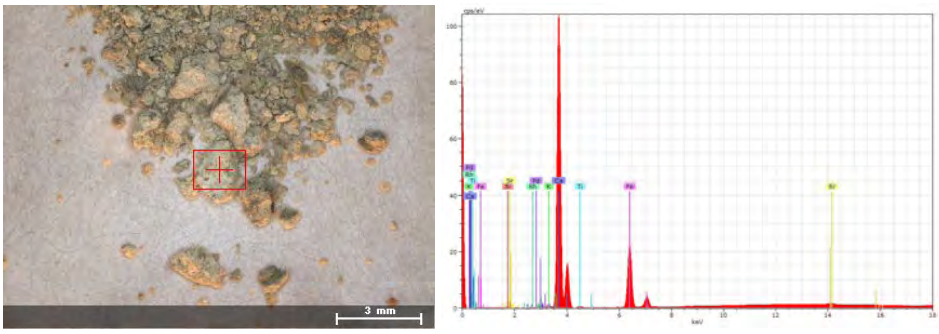


Figure 7.1.11 XRF spectrum of NB 16/11 ③

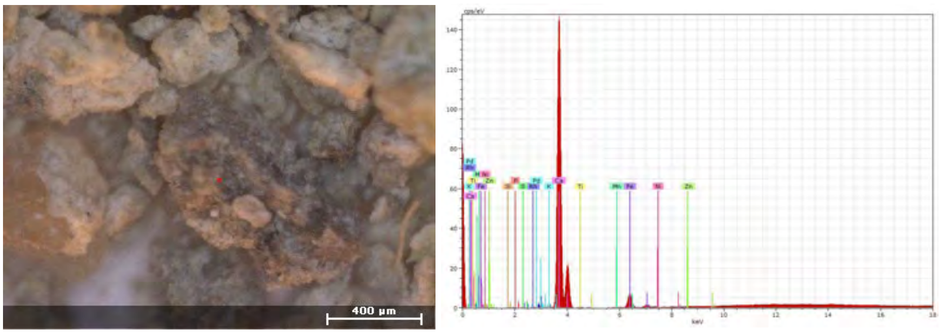


Figure 7.1.12 XRF spectrum of NB 16/11 ④

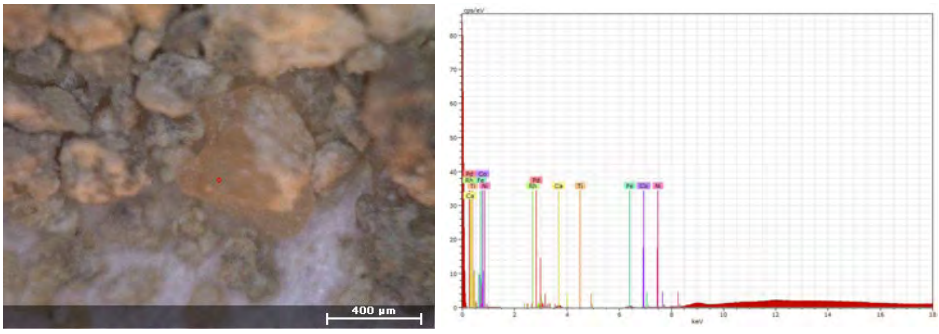


Figure 7.1.13 XRF spectrum of NB 16/11 ⑤

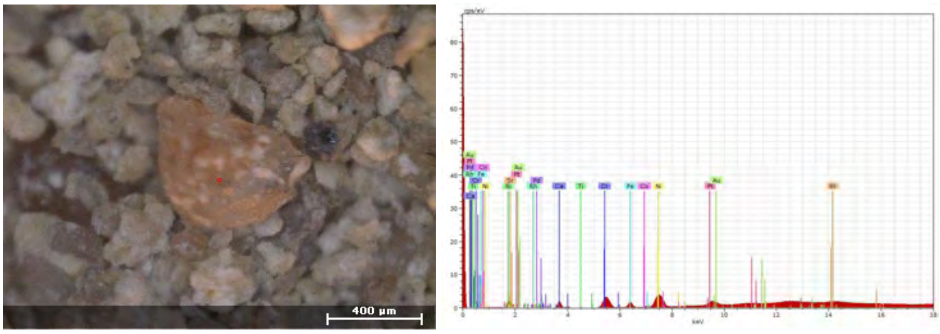


Figure 7.1.14 XRF spectrum of NB 16/11 ⑥

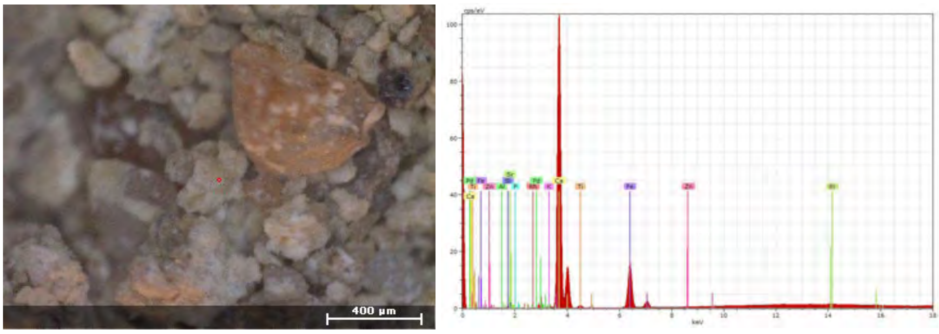


Figure 7.1.15 XRF spectrum of NB 16/11 ⑦

Figure 7.1.16 presents the XRD results. Calcite and quartz were identified by matching the reference data.

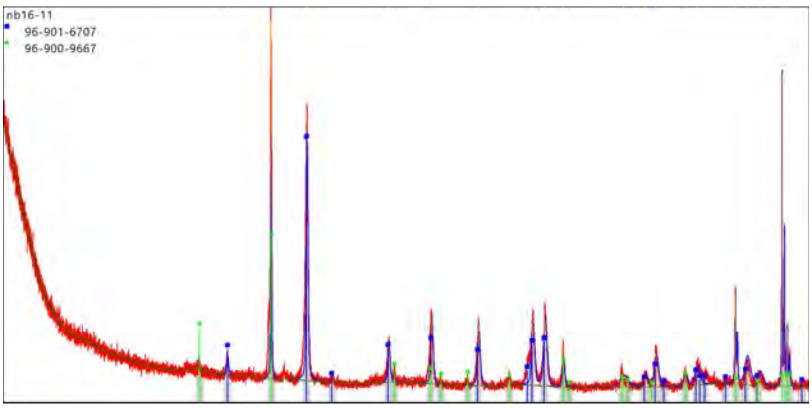


Figure 7.1.16 XRD result of NB 16/11. Blue and green symbols represent calcite and quartz, respectively.

3. NB 7/13

Figure 7.1.17 presents a microscopic image of NB 7/13. As with NB 14/7 B, most part of the sample was composed of fine white particles whose size was smaller than 10 μm. Moreover, tiny amounts of black and brown particles were observed in addition to white particles.

As presented in Figure 7.1.17, NB 7/13 was almost uniform. XRF was performed at three points on the sample (Figures 7.1.18–7.1.20). The spectra obtained at these points were similar, and primarily Ca, Fe, and Si were detected. The signal of Ti was high from the point ③ .

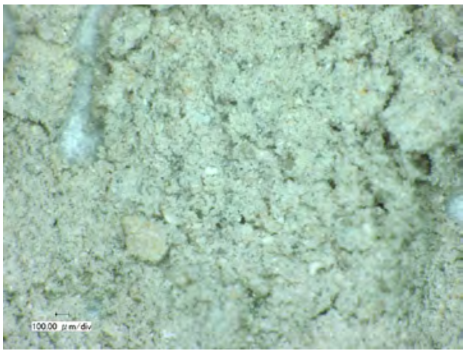


Figure 7.1.17 Microscopic image of NB 7/13

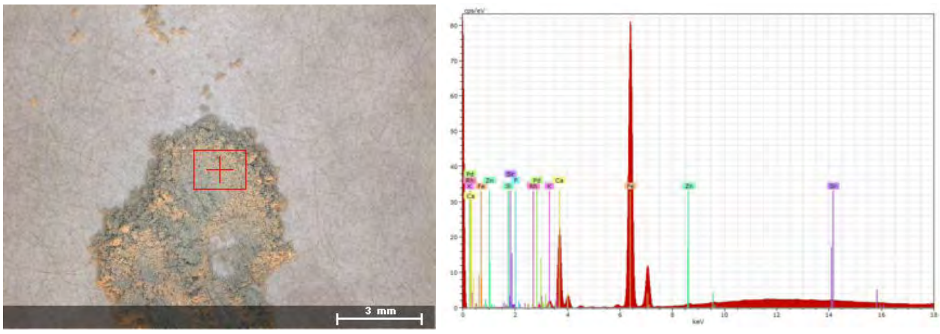


Figure 7.1.18 XRF spectrum of NB 7/13 ①

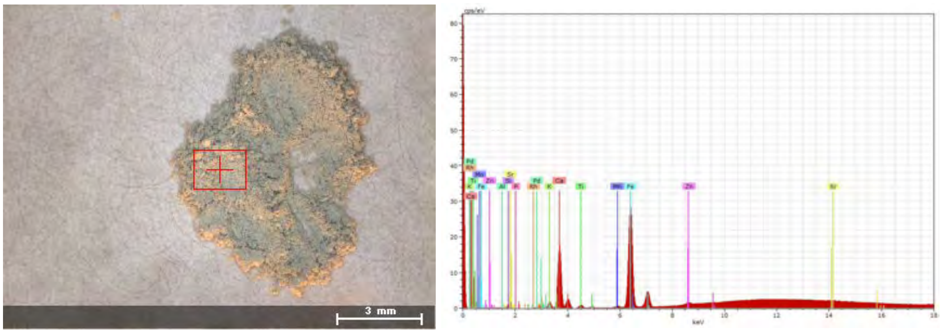


Figure 7.1.19 XRF spectrum of NB 7/13 ②

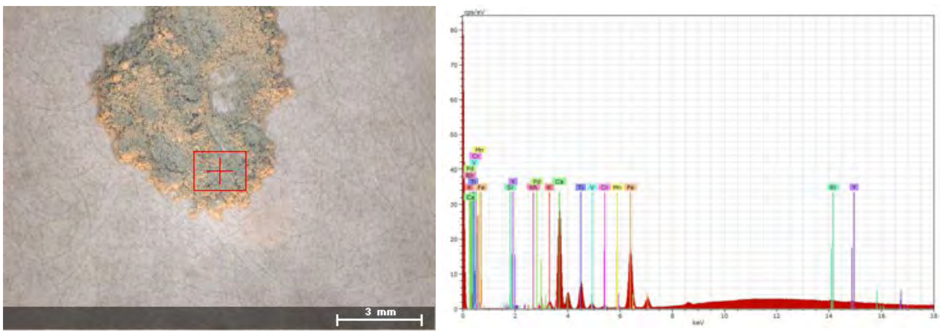


Figure 7.1.20 XRF spectrum of NB 7/13 ③

Figure 7.1.21 presents the result of XRD. Calcite and quartz were identified by matching the reference data. The patterns of the other peaks appeared to agree with the reference data for oligoclase.

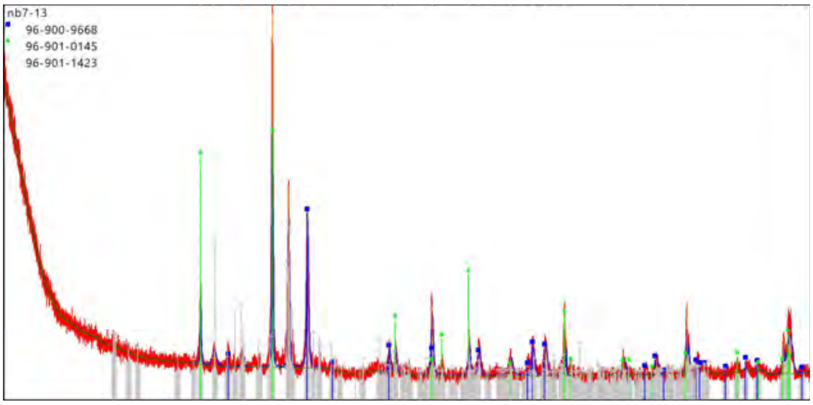


Figure 7.1.21 XRD result of NB 7/13. Blue, green, and gray symbols represent calcite, quartz, and oligoclase, respectively

4. SB 15/4 (more)

Figure 7.1.22 presents a microscopic image of SB 15/4 (more). Most part of the sample was composed of fine white particles whose size was smaller than 10 μm. Moreover, tiny amounts of black and brown particles were observed in addition to white particles.

Figure 7.1.22 Microscopic image of SB 15/4 (more)

As presented in Figure 7.1.22, SB 15/4 (more) was almost uniform. XRF was performed at three points on the sample (Figures 7.1.23–7.1.25). The spectra obtained at these points were similar, and primarily Ca, Fe, and Si were detected. The signal of Cr was stronger than that of the other samples.

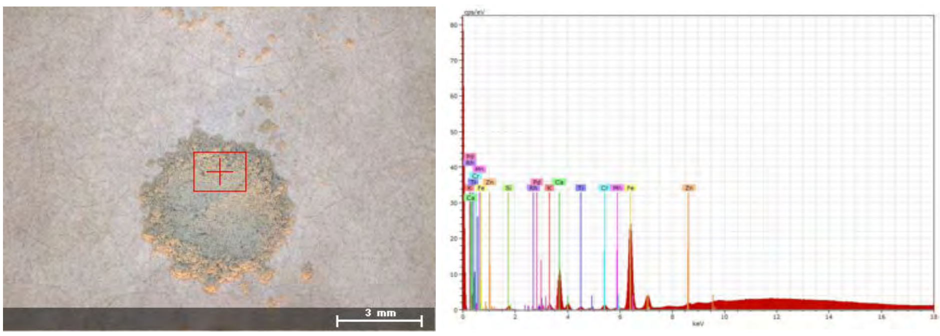


Figure 7.1.23 XRF spectrum of SB 15/4v(more) ①

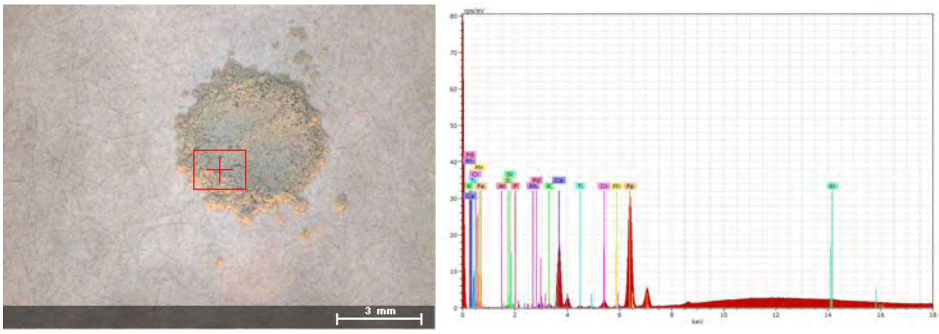


Figure 7.1.24 XRF spectrum of SB 15/4 (more) ②

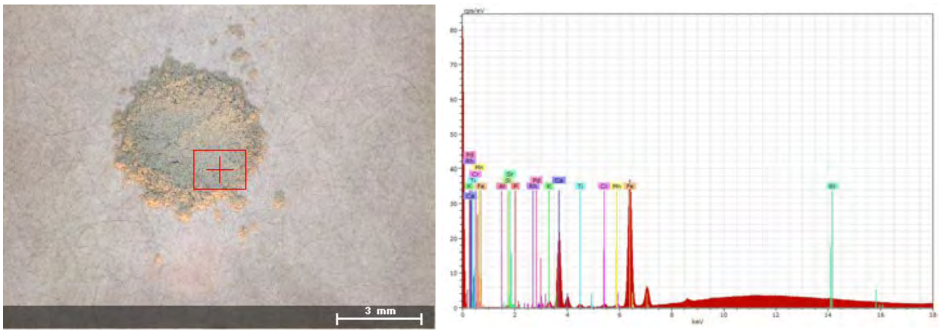


Figure 7.1.25 XRF spectrum of SB 15/4 (more) ③

Figure 7.1.26 presents the result of XRD. Calcite and quartz were identified by matching the reference data. The patterns of the other peaks appeared to agree with the reference data for oligoclase.

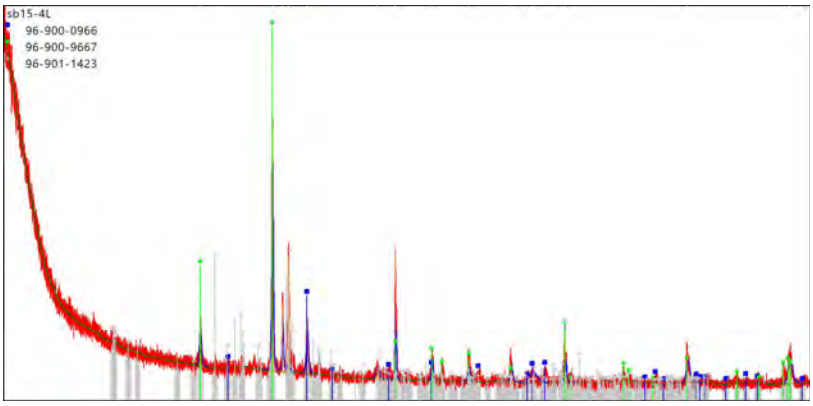


Figure 7.1.26 XRD result of SB 15/4 (more). Blue, green, and gray symbols represent calcite, quartz, and oligoclase, respectively

5. SB 15/4 (less)

Figure 7.1.27 presents microscopic images of SB 15/4 (less). This sample comprised particles with various colours (for example, white, gray, black, brown) and typical size of these particles was 100 μm.

The above microscopic images demonstrate that SB 15/4 (less) was composed of particles of various colours and sizes. XRF was applied to four points (① white, ② gray, ③ black, and ④ red). The obtained spectra are presented in Figures 7.1.28–7.1.31. Intensity of signals owing to Ca was high from the measurement points ① , however, the intensities were low for the other measurement points. The results of microscopic observations and XRF measurements suggest that SB 15/4 (less) was a mixture of calcite and soil.

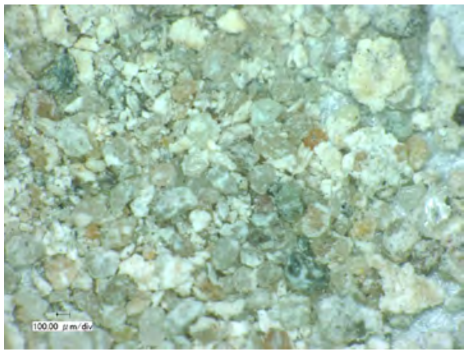


Figure 7.1.27 Microscopic image of SB 15/4 (less)

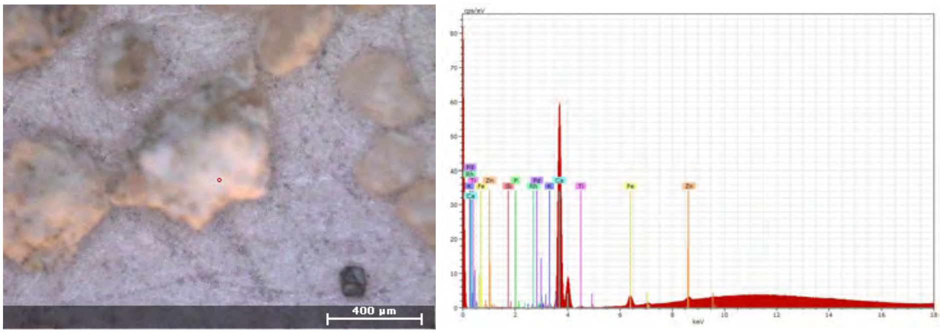


Figure 7.1.28 XRF spectrum of SB 15/4 (less) ①

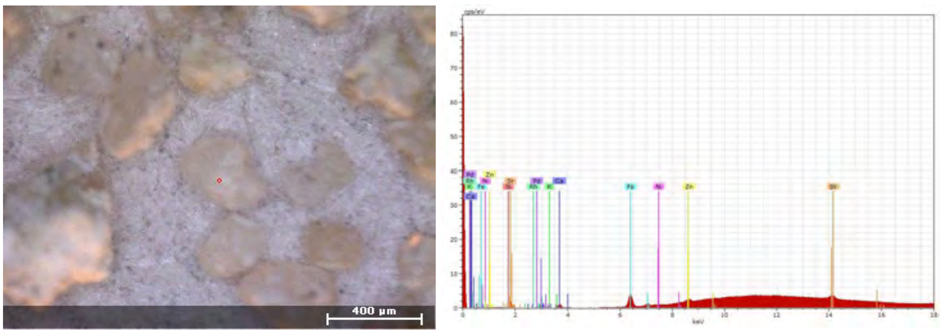


Figure 7.1.29 XRF spectrum of SB 15/4 (less) ②

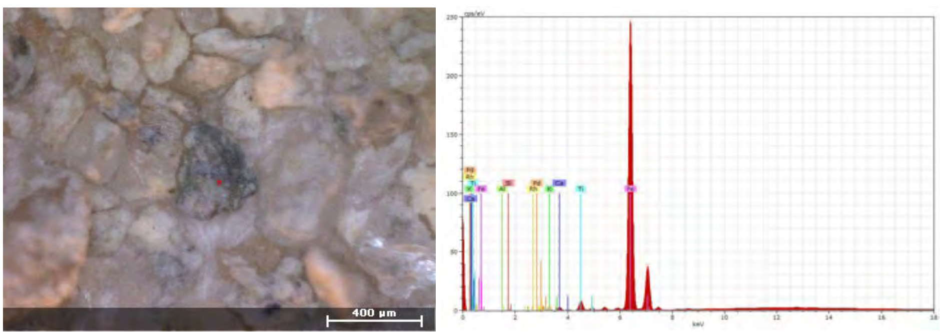


Figure 7.1.30 XRF spectrum of SB 15/4 (less) ③

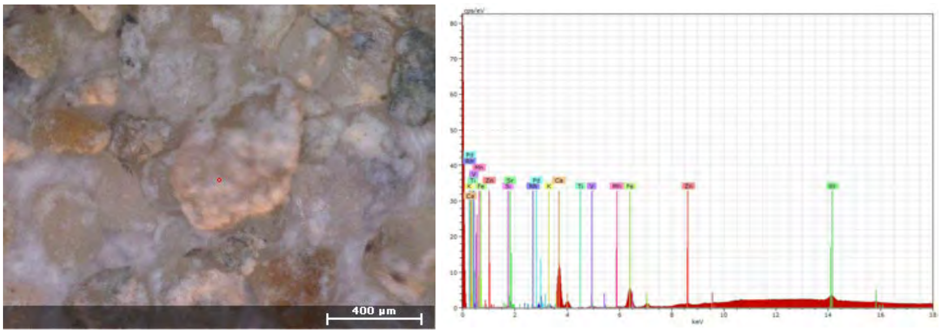


Figure 7.1.31 XRF spectrum of SB 15/4 (less) ④

Figure 7.1.32 presents the result of XRD. Calcite and quartz were identified by matching the reference data. The patterns of the other peaks appeared to agree with the reference data for oligoclase.

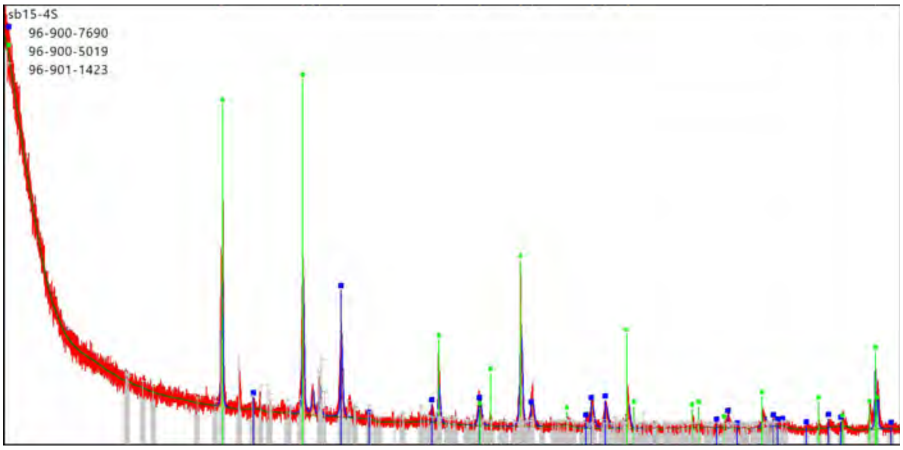


Figure 7.1.32 XRD result of SB 15/4 (less). Blue, green, and gray symbols represent calcite, quartz, and oligoclase, respectively

(5) Summary

From microscopic observations, the samples can be classified into two groups: I. Almost uniform and composed of fine white particles whose size was smaller than 10 μm (NB 14/7 B, NB 7/13, SB 15/4 (more)), and II. composed of particles with various colours and typical size of about 100 μm (NB 16/11, SB 15/4 (less)).

As a result of XRF, the intensity of the Ca signal was high when the measurement points were white or gray. However, it became low for measurement points displaying other colours. In addition to Ca, the intensities of the signals from Fe and Si were high.

Both calcite and quartz were identified in all the five samples using XRD. The patterns of the other peaks appeared to agree with the reference data for oligoclase.

From the above results, it can be concluded that the white and gray components in the five samples were calcite, and the samples were a mixture of calcite and soil.

One factor of interest regarding the composition of the samples was the presence of organic matter. However, no organic matter (except for the dead bug presented in Figure 7.1.8) was observed by microscopy. Although FT-IR was applied to the samples, the results are not reported here because no clear evidence was obtained.

7.2. Analysis of Base Structure Soil Samples

NISHIDA Noriyoshi

(1) Purpose of Analysis

The base structure of Ta Nei Temple was built with exterior sandstones, laterite substrate blocks, and compacted soil layers beneath them. The purpose of this analysis was to determine the characteristics of the materials composing the compacted soil layers by analysing soil samples taken during the soil sampling (see Section 6.1) applied to the compacted soil layers.

(2) Samples for Analysis

The soil sampling was conducted from the level of the bottom surface of the laterite substrate blocks to a depth of 700 mm, where the solid layer considered as basement was hit. A total of 14 target soil samples gained from the soil sampling at 50-mm depth intervals were taken. As the soil sampling was conducted without dismantling the base structure to check the strength of the inner compacted soil layers, the profile of those layers was not visually confirmed. While the inner compacted soil layers are assumed to have been compacted down little by little, and not at once with a large amount of soil, the thickness of each tamped layer is not known. Therefore, the samples which were separated by 50 mm did not match the thickness of the compacted layers. This was a limitation of the analysis due to the way of sampling.

Sample List

No. 1: 0 mm*- 50 mm
 *at bottom surface of laterite substrate
No. 2: 50 mm - 100 mm
No. 3: 100 mm - 150 mm
No. 4: 150 mm - 200 mm
No. 5: 200 mm - 250 mm
No. 6: 250 mm - 300 mm
No. 7: 300 mm – 350 mm
No. 8: 350 mm – 400 mm
No. 9: 400 mm - 450 mm
No. 10: 450 mm - 500 mm
No. 11: 500 mm - 550 mm
No. 12: 550 mm - 600 mm
No. 13: 600 mm - 650 mm
No. 14: 650 mm - 700 mm (maximum depth)

The samples were numbered starting from the top layer closest to the laterite substrate. Above is a list of the sample numbers and their corresponding layer depths.

(3) Analysis Methods

The 14 samples described above were analysed by visual observation using a polarizing microscope, colour measurement, X-ray fluorescence analysis, and particle size distribution analysis. Below are details of the analysis methods employed.

1. Polarized light microscopy

Equipment: Leica DM 2500 LED optical microscope with polarization unit

2. Colour measurement

Equipment: Konica Minolta CM-2600d spectrophotometer

Measurement conditions: L*a*b* colour measurement (CIE 1976 L*a*b* Colour space), specular reflection exclusion mode, probe diameter 3 mm

Powdered samples were held and pressed flat between two glass slides for colour measurements, and colour measured through the slides.

3. X-ray fluorescence analysis

Analysis equipment: Bruker M4 TORNADO micro-XRF spectrometer

X-ray tube specifications: Rhodium; Tube voltage: 50 kV; Tube current: 200 μA; X-Ray irradiation diameter: 20 μm; Atmosphere: Vacuum

The soil samples were held between two sheets of Mylar® (polypropylene terephthalate (PET)) film and fixed for measurement. Measurement area was set as 6 mm by 6 mm. A total of 3,600 spectra were taken by dividing the measurement area into 100 μm by 100 μm subareas. The elemental quantification was conducted by averaging the spectra gained.

4. Particle size distribution measurement

Analysis equipment: Seishin LMS-2000e laser diffraction particle size analyser

Measurement conditions: wet operation; tap water was used as dispersion medium

Measurement was conducted repeatedly 3 to 5 times per sample.

(4) Analysis

1. Polarized light microscopy

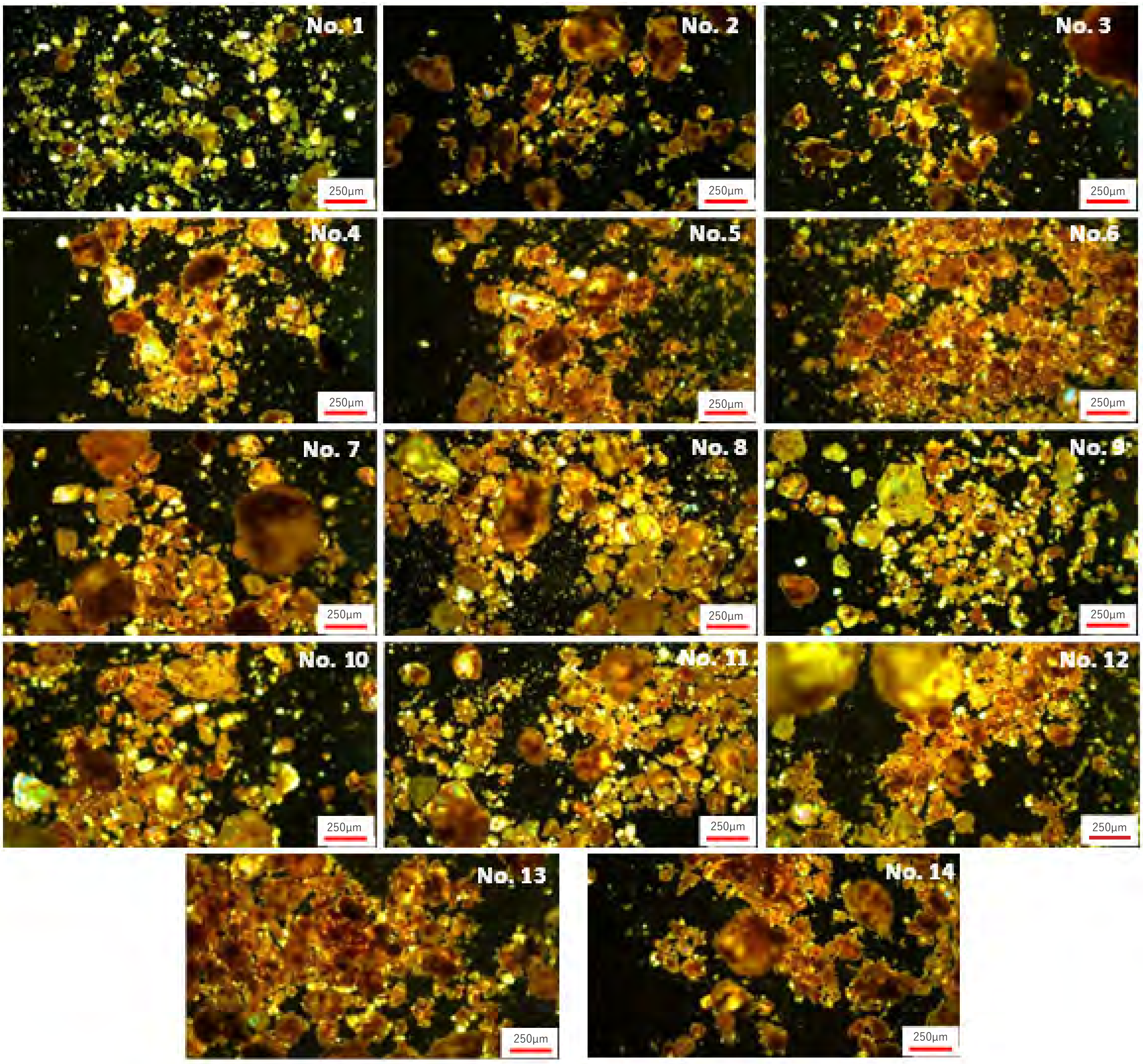


Figure 7.2.1 Polarizing microscope images of the soil samples

Figure 7.2.1 shows polarizing microscope images. Greenish particles were recognised as derived from quartz, and brownish particles from iron oxide, iron hydroxide, aluminium oxide, aluminium hydroxide, and others. The majority of the particles were from some μm to some dozen μm in diameter, which means that the particles were silt. Large grains of sand over 100 μm diameter were also recognised. There were no clear differences among the samples based on the depth at which they were taken.

2. Colour measurement

Table 7.2.1 and Figure 7.2.2 show the outcomes of colour measurement. Though the samples taken from near the surface tended to have higher brightness and lower chromaticity, no clear tendency relative to the depth was recognised.

Table 7.2.1 Colour measurement data (CIE 1976 L*a*b* Colour space)

Sample No.	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10	No. 11	No. 12	No. 13	No. 14
L*	52.1	49.5	48.0	48.4	43.8	46.1	47.6	45.8	46.9	47.2	48.4	50.1	53.7	51.8
a*	7.8	9.1	9.7	12.1	13.9	13.6	14.0	13.7	13.2	13.7	13.6	13.8	11.4	12.2
b*	19.8	21.0	20.4	25.2	26.1	26.0	26.2	24.6	23.6	25.0	26.4	28.0	26.6	25.3

3. X-ray fluorescence analysis

Table 7.2.2 and Figure 7.2.3 show results of X-ray fluorescence analysis. Every sample had higher Si density and lower Fe and Al densities compared to the lateritic soil. The Si density can be seen to increase and Al density to decrease with lower depth of samples taken. The sample from 350 - 400 mm (No. 8) had remarkably higher Si density and lower Fe density compared to the sample No. 7 and No. 9. In addition, the sample from 450 - 500 mm (No. 10) had remarkably lower Si density and higher Fe density, compared to the sample No 9 and No. 11. Therefore, it is possible that the soil bedding was disturbed at these depths.

Table 7.2.2 X-ray fluorescence analysis data of the soil samples (%)

	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8	No.9	No.10	No.11	No.12	No.13	No.14
Si	79.5	80.4	80.9	81.8	82.0	82.4	83.8	87.0	85.0	80.4	87.5	88.5	87.1	87.2
Fe	5.3	5.4	5.8	6.0	6.8	6.1	5.6	4.2	4.8	7.3	4.2	5.0	6.4	6.7
Al	12.1	11.6	10.7	10.0	9.4	9.4	8.7	7.3	8.5	9.8	6.7	5.2	5.3	5.0
Ca	0.7	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.4	0.4	0.3	0.3	0.3	0.2
Ti	0.9	0.8	0.9	0.7	0.7	0.7	0.6	0.6	0.7	0.7	0.6	0.6	0.6	0.6
K	1.6	1.4	1.2	1.0	0.8	0.9	0.8	0.6	0.7	1.3	0.6	0.4	0.3	0.3

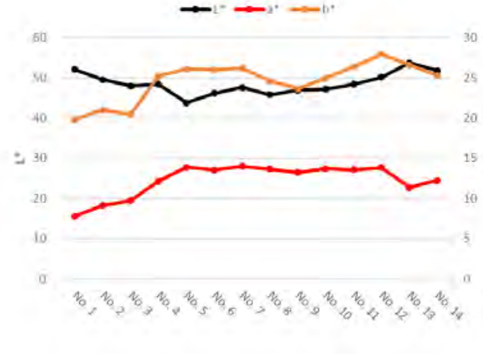


Figure 7.2.2 Colour measurement graph

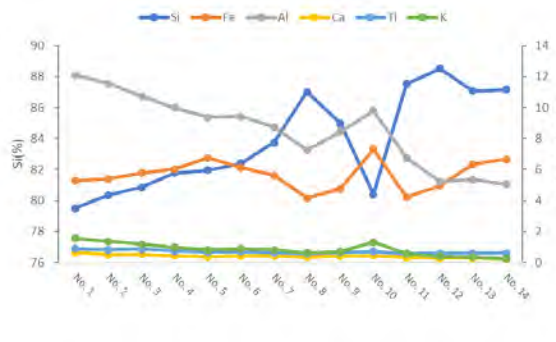


Figure 7.2.3 X-ray fluorescence analysis of the soil samples

4. Particle size distribution measurement

Table 7.2.3 shows the average particle diameter and Figure 4 shows particle size distribution. Most of the samples showed bimodal distributions with peaks at particle diameters of around 10 μm and 200 - 300 μm. This suggested that the samples were mixtures of sand (for which particle diameter is defined as 75 - 2,000 μm) and silt (particle diameter defined as 5 - 75 μm). For the bimodal distributions, the average particle diameter did not have directly comparable meaning to those of the monomodal distributions. Still, the fact that sample No. 8 (350 - 400 mm depth) had the largest average particle diameter indicates, for example, that it had higher proportion of sand compared to the other samples from different depths. Furthermore, based on the definitions based on particle sizes, above,approximations of the ratio between silt and sand in each sample are shown in Figure 7.2.5.

Table 7.2.3 Average particle diameter of soil the samples (μm)

Sample No.	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8	No.9	No.10	No.11	No.12	No.13	No.14
Average particle diameter	59.9	50.7	69.6	33.7	44.9	60.2	60.6	162. 4	106.9	65.7	68.1	102.6	25.2	32.1

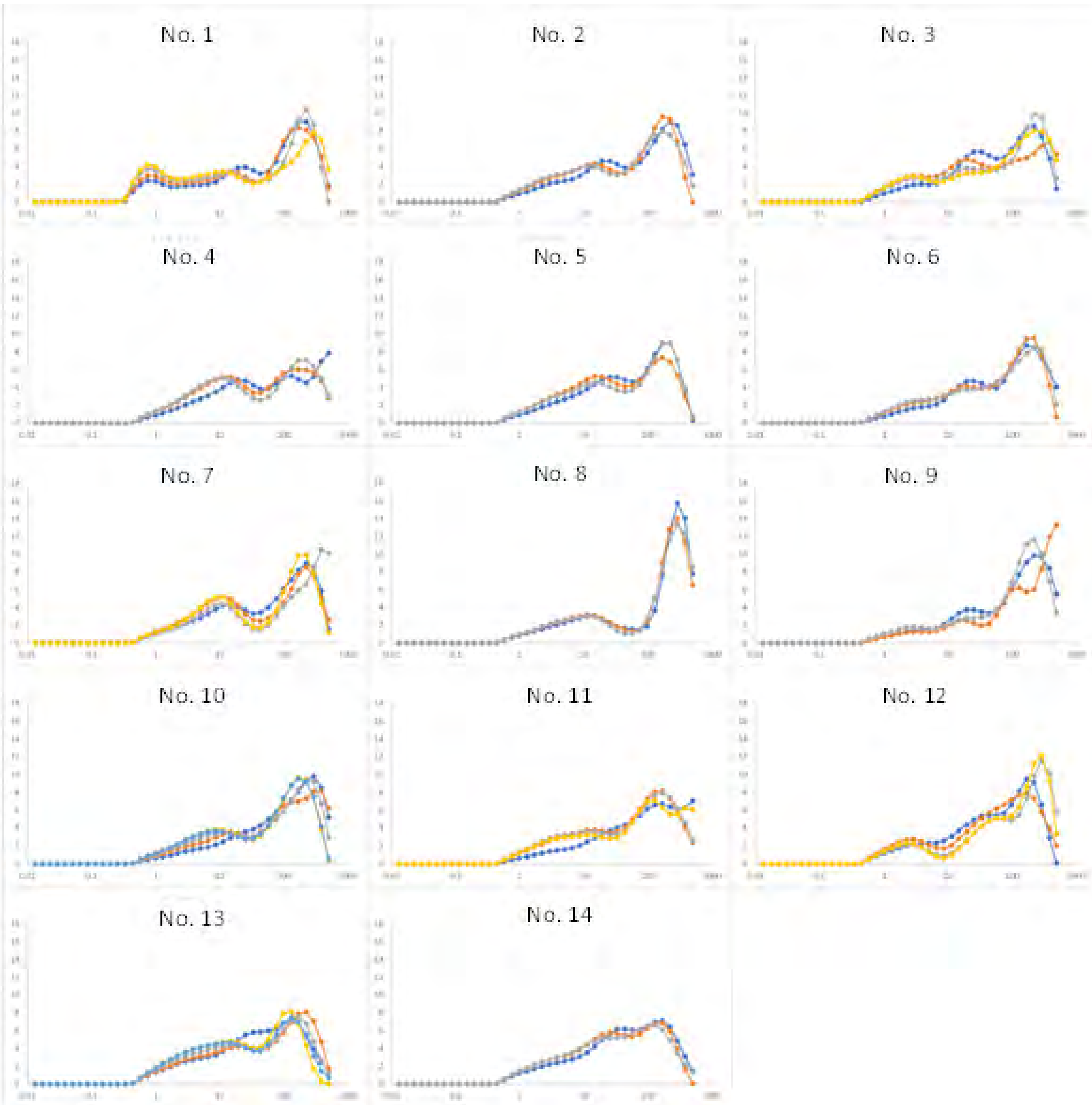


Figure 7.2.4 Analysis of particle size distribution of the soil samples (x-axis, μm; y-axis, %)

The proportion of sand peaked at the depths of 350 mm and 450 mm (sample No. 8 and No. 9). This indicates that some disturbance possibly occurred at the layers by sampling or during original construction. Also, the proportion of silt peaked at the depth of 600 - 700 mm (deepest) (sample No. 13 and No. 14). This fact suggests that some disturbance possibly occurred at these layers or of some influence from the basement layer.

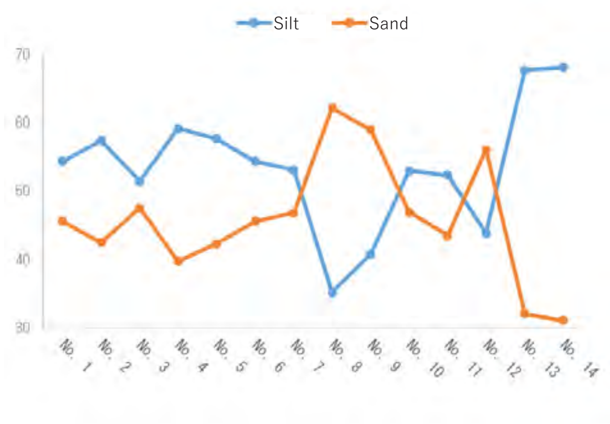


Figure 7.2.5 Ratio between silt and sand in each sample

(5) Conclusion

As the profile of the inner compacted soil layers could not be visually inspected, we conducted particle size measurement and elemental analyses to determine the structure of the rammed earth; however, no clear structure was confirmed. The elemental composition differed based on the depth at which the samples were taken, while discontinuous layers were observed at 350 - 400 mm and 450 - 500 mm depth. In addition, at the depth of 350 - 450 mm, the proportion of sand was larger and the ratio of silt to sand was obviously different from the other layers. One possible reason for this is that discontinuous layers were formed because the soil was once tamped down at that depth. Furthermore, the fact that the deepest layers of 600 - 700 mm had larger proportion of silt suggests the possibility that the soil quality had changed at around 600 mm depth. Neither consideration, however, was confirmed, due to a lack of information. Further investigation is needed based on soil samples collected at smaller depth intervals, or further analysis such as X-ray crystallography or Raman spectroscopy.

Chapter 8

Discussion on Restoration

8.1. Investigating the Damage Mechanisms

TOMODA Masahiko

The deformation of the East Gate before restoration is described in Section 4.1 on the pre-dismantling survey. Although the superstructure exhibited a considerable wall slant and joint gaps between the stones, the base structure did not show any signs of significant irregular ground subsidence, despite some misalignment of the stones at the base structure's outer periphery and uneven flooring (Figure 8.1.1). Nonetheless, preliminary excavations around the base structure revealed that the roots of adjacent trees had reached the base structure's interior on the western side, which was assumed to be the likely cause of phenomena such as the movement of the stones making up the base structure and outflow of the internal soil fillings.

As for the walls of the superstructure, contrasting with the good state of the joints between the stones on the insides of the wall, longitudinal continuous joint breaks were observed at all external and internal corners where walls intersect orthogonally, resulting in all eight walls forming the cross-shaped plane falling inwards, while the eastern and western gable ends were sloping outward (Figure 8.1.2).

Looking at the roof of the corbel arch structure, it is assumed that the upper parts of the gable walls on the three sides, except the eastern side, collapsed outwards. Subsequently, the roofing of the vault section, having become destabilised at its ends, lost balance in conjunction with the deformation of the walls on both sides collapsing inwards. Finally, the roof collapsed towards the building's interior. Nevertheless, considering how not all materials making up the upper centre of the roof were indoors, having collapsed also on the southwestern side and elsewhere outside of the building, it is highly likely that vegetation growth and/or artificial destruction might have contributed to the roofing displacement.

In light of matters revealed during the dismantling survey, we summarise the structural defects that caused the East Gate's partial collapse as follows:

1) Deterioration and loss of laterite and soil filling layers owing to the partial deformation of the base structure and ingress of rainwater into the base structure as a result of this deformation.
2) Insufficient joining and meshing of stones at the ends and corners of the main body walls.
3) Inappropriate joint placement, such as small stones in locations with high stress following deformation of the main body.
4) A corbel arch structure that loses stress balance immediately following stone displacement.

Figure 8.1.1 Displacement of the stones on the base structure's outer periphery

Figure 8.1.2 Continuous open joints in the vicinity of an external corner

8.2. Restoration Policy Approval Process

TOMODA Masahiko

(1) Report and recommendations at the 32nd Technical Session of the ICC-Angkor in June 2019

After excavating the area around the base structure down to the former ground level and completing the recording of the existing state of the East Gate through 3D scanning and photogrammetry, ICC-Angkor ad hoc group of experts visited the site on 2 June, 2019 (Figure 8.2.1). This visit was held during the period when efforts were made to organise materials scattered around the site from the East Gate. The following explanation provides details on the site's condition at that time:

[The need for restoration and the current situation]

- The East Gate serves as the original main gate entrance to the temple and is the initial structure encountered by visitors, playing a pivotal role in understanding the site.
- Due to the collapse of the corbel vault and subsequent wall deformation, the East Gate is currently in an unstable state.
- The original stones constituting the collapsed vault are scattered both inside and outside the building, but the majority of the material is in good condition.

[Basic Restoration Policies]

- The primary goal of the restoration is to bring the East Gate back to a structurally sound and safe state, allowing visitors to pass through and explore the temple.
- Considering that the collapse of the vault was the main cause of stability loss, the vault will be reconstructed by returning the scattered original materials to their original positions, with minimal supplementation of new materials.
- Before rebuilding the vault, addressing wall deformations is necessary. The walls will be dismantled gradually in layers, determining the required extent of dismantling while analysing the deformation. Simultaneously, the need for reinforcing the walls and base structure will be considered.

Based on the results of the on-site inspection and the explanation provided, the following recommendations were made at the 32nd Technical Session of the ICC-Angkor (11–12 June, 2019).

Figure 8.2.1 Site visit by the ICC ad hoc group of experts (June 2019)

Figure 8.2.2 Presentation at the ICC session in June 2019

11. Ta Nei Temple

The ad hoc group of experts:

a) Welcomes the overall quality of cooperation prevailing between the Japanese and the APSARA National Authority teams.

b) For restoration of the East Gate, recommends that the intervention be based on the principle of anastylosis, i.e. in situ dismantling and reassembly in identical fashion the structures given the small dimensions of this gate, a thorough understanding of it by means of analysis and a detailed survey, including the extent of problems above ground and in the foundation, the small number of missing stones onsite or that have fallen off and been inventoried, and the obvious resemblance to the West Gate.

i) That process will enable verification of the quality of the gate's foundation by means of exploratory borings, providing a basis to develop a possible consolidation project. At the same time, the water level and flow pattern will also be identified. The few dead trees in the immediate proximity of the gate, with their roots cut, are now a threat, so must be cleared away. That will finally make it possible for visitors to access the temple through the original entrance gate.

c)d)e) (omitted)

(2) Report and recommendations at the 33rd Technical Session and the 26th Plenary Session of the ICC-Angkor in December 2019

Following the completion of the roof dismantling that began in September 2019, the dismantling of the walls, which started in October 2019, was concluded. Subsequently, the ICC-Angkor ad hoc group of experts made a second visit on 3 December, 2019, when archaeological excavations were underway on the outer periphery of the base structure (Figure 8.2.3). The following are the principal contents of the explanation and questions.

[Project progress]

・Explained the role of the East Gate restoration in the master plan and highlighted the progress made since the last visit in June 2019. Confirmed the dismantling work of the roof and walls, including the applied documentation methodologies at each stage. → No specific issues.

[Current situation of the East Gate]

・Explained that there is unevenness throughout, especially with the stones on the outer periphery having moved outwards, causing joint gaps. → (Bouchenaki). Has vegetation not been a significant factor in this? There is a particular concern that lacunae may have formed in the soil layer of the base structure owing to invasive tree roots.

[Soil bearing capacity survey]

・Explained the methods and location.
→ No specific issues.

[Excavation survey]

・Explained that some stones will be removed at the south-eastern corner, and the internal structure will be checked.

Figure 8.2.3 Site visit by the ICC ad hoc group of experts (December 2019)

→ Confirmed that a partial sub-trench will be installed at the side wall of the base structure, and the excavation will proceed to the base of the bottom stones. If the underground stones do not seem to have moved, there will be no need to dig deeper.

[Base structure restoration policies]

・Explained that the plan is to adjust the unevenness at the top without moving the bottom part of the base structure and that if the internal soil layer is sufficiently compacted, it can be left untouched while improving evenness mainly in the laterite layer, minimising the use of concrete. → (Bouchenaki). It is a small building and does not suffer from the same water issues as the causeway of Angkor Wat, so concrete should not be used. Please discuss a method that can serve as a model for the restoration of similar buildings.

・(Pallot) To what extent will the base structure be dismantled? → This has yet to be decided, but we would like to avoid dismantling the issue-free parts as far as possible.

[Repairing dismantled materials]

・Explained the idea of using simple bonding for small pieces and insertion of the steel bar reinforcement for joints that require structural strength. → Understood.

・The stone repair will be handled by the APSARA team trained by the University of Palermo, Italy. As is common in Angkorian architecture, owing to the construction procedure of first piling and then sculpting the stones, much of the material has weak edges; thus, dismantling is not really desirable. → (Bouchenaki). I understand that dismantling may be unavoidable for this building owing to the deformation situation and other factors.

・(Pallot) Question on the numbering system for the stones.

[The approach and the entrance terrace]

・Explained the remains confirmed by excavations. Also, clarified that the survey has been suspended for the time being to focus on the restoration of the East Gate. The northern and southern wings of the terrace are to be surveyed after the restoration is completed, following which maintenance policies will be considered. → Understood.

Based on the results of the on-site inspection and the explanations provided, the following recommendations were made at the 33rd Technical Session and the 26th Plenary Session of the ICC-Angkor (10–11 December, 2019).

1. Restoration work on East Gate of Ta Nei Temple

The ad hoc group of experts expressed its appreciation for the quality of the preliminary work and care given to the dismantling of the upper structures of the edifice after preparing a risk map and doing a systematic survey of all the blocks. Numbering them, and recording their placement for an anastylosis operation have been done with great precision. An action plan for the way forward was submitted to the group of experts, who make the following recommendations:

a) to move ahead with archaeological research on the monument perimeters to get a comprehensive vision of the condition of the foundation and possible weathering of the laterite blocks that has led to deformation of the stone footings at the base of the monument.

b) to move ahead with the geological research to properly grasp the soil levels and thus assess what has given rise to the deformation, notably the subsidence of the monument's southeast section.

c) to clear the causeway access and see in what way the Cruciform Terrace now revealed is connected to the East Gate of the temple.

d) to look into the possibility of putting in pedestrian access to Ta Nei temple from Ta Keo temple, based on an upstream study of what may have been used historically.

(3) Visit by the Japanese and French chairpersons in October 2020

On October 24, 2020, Christophe Gigaudaut, the French chairman of the technical session, conducted an on-site inspection due to the COVID-19 pandemic preventing the ICC-Angkor from convening and the ad hoc group of experts from visiting. As the Japanese members were also unable to travel, APSARA provided explanations on-site based on jointly prepared materials. At the time, APSARA was in the process of reassembling the upper part of the building while engaging in online discussions with the Japanese team (Figure 8.2.4). The following content was mainly explained during this visit:

- Work process and progress
- Geological survey of the base structure based on the previous recommendations and results thereof
- Policy and construction details for the improvement of the base structure
- Reinforcement policy and construction details based on structural calculations of the superstructure
- Methods for repairing damaged parts
- Future plans

The 34th Technical Session of the ICC-Angkor was held on January 26, 2021, where APSARA staff reported on the progress of the restoration of the East Gate. The recommendations of the ad hoc group of experts following the meeting made no mention of Ta Nei Temple. A Zoom meeting with the ad hoc group of experts was held on June 28, 2021, followed by the 35th Technical Session and the 28th Plenary Session on March 24–25, 2022, the 36th Technical Session and the 29th Plenary Session on December 15–16, 2022, and the 37th Technical Session on June 12–13, 2023. Although all these meetings combined in-person and online attendance, none included reports or recommendations pertaining to the East Gate of Ta Nei Temple. In the future, the plan is to provide an on-site explanation to the ad hoc group of experts on the completion status of the East Gate and a final report on the restoration of the East Gate at a Technical Session of the ICC-Angkor, along with explanations of future project plans.

Figure 8.2.4 Online discussion between APSARA and TOBUNKEN during the COVID-19 pandemic

8.3. Implementation Methods

TOMODA Masahiko

In alignment with the restoration policies outlined in Section 2.1, this section details the practical implementation methods that were adopted following consultations between the Japanese and Cambodian teams. The discussion refers to the damage mechanisms identified for the East Gate in Section 8.1 and incorporates the recommendations of the ICC-Angkor ad hoc group of experts outlined in Section 8.2.

(1) Anastylosis

All walls exhibited an inward slant, and numerous stones along the outer periphery, supporting the walls atop the base structure, were displaced and tilted. Consequently, it became imperative to dismantle, at a minimum, the affected area to rectify the displacement. Both teams aimed to minimise potential damage to the stones during the dismantling process, and the extent of dismantling was determined after a thorough examination of the nature and causes of the deformation.

Following the completion of the dismantling, from the roof down to the second wall layer from the bottom, excavations were carried out in December 2019 to verify the base structure in the south-eastern and north-western corners. The exterior sandstones of the base structure on the south-eastern side had been dismantled in advance to check the condition inside the base. In two locations near the centre of the indoor floor, the sandstone pavement was removed to expose the upper surface of the laterite beneath. Subsequently, a penetration test was conducted to assess the strength of the base structure's interior and ground. The results indicated that the laterite inside the base structure, inner soil filling, and base structure ground directly below the walls exhibited sufficient strength to support the superstructure. However, it was confirmed that the laterite had deteriorated considerably in some areas.

(2) Base structure improvement

Significant deterioration of laterite was observed in the western wing and the northern half of the eastern wing, extending beneath the sandstone floor pavement and the lower layers behind the external sandstone. In these areas, the presence of detached joints in the sandstone material of the base structure exterior, coupled with vegetation growth and rainwater ingress, likely contributed to the laterite's deterioration. Tree roots had penetrated into the joints in the northern half of the western wing, necessitating the dismantling of the base structure exterior to remove them (Figure 8.3.1).

Since the deteriorated laterite was not sturdy enough to withstand dismantling, it was decided to replace it with new material. During this process, the number of joints was reduced, and stability was enhanced by replacing sections with several small blocks of laterite with larger single blocks. In areas where the lower laterite layer was dismantled and replaced, tamping was performed with lime mortar directly below, and lime mortar was used to fill spaces between stones and between the inner soil filling and peripheral stones. The laterite and soil filling under the interior floor were considered harmless to the support of the superstructure, so they were left in place, even in areas that had deteriorated.

Due to partial subsidence in the dismantled base structure area, adjustments were made during reassembly. Adjusting the northern half of the western wing, done from the bottom of the base structure, posed challenges but was eventually completed within the determined scope. When adjusting the level of the sandstone in the layer corresponding to the floor, efforts were made to

Figure 8.3.1 Conditions inside the base structure during the dismantlement

adjust by cutting the upper surface of the new laterite without using lime mortar as much as possible. Regarding the excavated area of the base structure's outer periphery, rebuilding followed the original method, with excavated soil being mixed with laterite or sandstone fragments before manual tamping.

(3) Structural reinforcements

After modelling the completed building and calculating the structure of the superstructure, without considering seismic forces, no issues were confirmed, provided that every stone is rigidly settled in its original position without any displacement. Preventing long-term stone movement was considered the most crucial requirement for improving structural stability. The easiest way to fix the stones, without affecting their external appearance, was to insert connecting elements between them. However, such reinforcement causes irreversible damage to the original stone, so the goal was to minimise this as much as possible. Consequently, the decision was made not to reinforce the central part of the walls, where there had been little deviation between the stones before restoration. Instead, the focus was on fixing the base structure's outer periphery, the inner and outer corners near the upper edges of the walls, the entrance pilasters on the left and right sides, the vault intersection at the centre of the roof, and the finial, where displacement had been significant.

Initially, the Japanese side proposed a method of resisting lateral slippage by inserting short metal dowels between the upper and lower stones to fix them to each other. This would minimise damage to the stone, and it was assumed to have the merit of being barely visible when applied to a stone with an exposed upper surface. However, APSARA was reluctant to use this method because it had not been widely employed at Angkor, given the time and effort required to accurately align the upper and lower drilling positions and because stability would remain uncertain as adjacent stones cannot be directly fixed to each other. Thus, they decided to adopt mainly a method of fixing the stones from the top with stainless steel clamps, which had already been extensively used.

At the intersection of the vaults, a square surface is formed by the parallel arrangement of long sandstone blocks. To unify the entire surface and ensure rigidity, stainless steel rods that penetrate adjacent stones in the short direction were inserted.

Fixing by dowels

Fixing by clamps

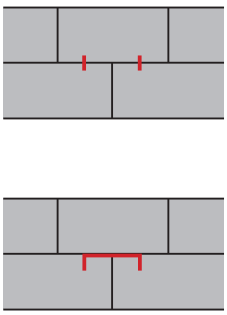


Figure 8.3.2 Schematic stone fixing pattern using dowels and clamps

Figure 8.3.3 Metal clamp fixing on the eastern lintel's upper surface

(4) Treatment for damaged members

The repair of damaged stones is detailed in Section 9.1. This subsection briefly touches on the specifications of parts particularly important for structural stability—the long members subjected to bending stress that had broken, such as the upper frame of the entrance, lintel, and central part of the roof.

For the upper frame of the entrance and lintel, holes were drilled through the entire length near the centre of the cross-section to prevent reinforcements from being exposed. Stainless steel rods with screw cutting on both ends were inserted and fixed by tightening nuts. The lintel was secured using stainless steel clamps on the upper surface, attached to the stones behind to prevent it from falling forward (Figure 8.3.3).

Considerable weight is applied from the top where the topmost layer of the vault from all sides meets at the centre of the roof. As people would be passing directly underneath, it was reinforced by inserting stainless steel rods into the stones at the top of the vault as an additional safety measure (Figure 8.3.4). This resulted in an unexpected mistake when part of the reinforcement came to be exposed on the interior. Nonetheless, it is assumed that sufficient reinforcement was achieved in terms of safety.

(5) Supplementing missing parts

As part of the restoration, it was possible to recover most of the original materials, including those that had collapsed, allowing much of them to be reused in their original positions. Some of the original materials were only partially recovered, and considerably defective materials had to be replaced with new ones, but this only applied to a small part of the total (Figure 8.3.5).

In some instances, the original materials could not be found. This was true for part of the base structure's outer periphery, near the upper end of the pediments on four sides, the lintel on the eastern side, and the colonettes on the eastern and western sides. Of these, new sandstone was supplemented at estimated dimensions to the base structure, lintel, and colonettes but not to the pediment ends. This decision was made according to the principle that defects should be supplemented if they pose risks in terms of structural stability and deterioration, while defects of primarily aesthetic import should not be supplemented.

Possible reasons for the disappearance of the materials at the pediment ends are that they were easy to move and fell down at an early stage or were buried somewhere in the temple complex away from the East

Figure 8.3.4 Insertion of stainless steel rods at the centre of the roof

Figure 8.3.5 Supplementary new stones at the southern pediment (work in progress)

Gate, so they may be found in the future. In that case, it is expected that they will be returned to their original positions. The head of the figure at the centre of the pediment seems to have been lost due to theft, supported by the fact that it appears in old photographs, but a decision was made not to replace it in the hope that it would be recovered in the future (Figure 8.3.6). The biggest mystery surrounding this building is the absence of lintel material on the eastern side. The fact that not even fragments have been found suggests that it was removed in its entirety in the past, but no relevant records have been found in EFEO's journals or elsewhere.

(6) Finishing new supplementary materials

Regarding the aforementioned addition of supplementary and replacement materials, the outline is processed to the extent that it is considered sufficiently probable vis-à-vis continuity with surrounding materials, but details are not reconstructed by estimation. This was discussed at recent ICC meetings. For example, among the recommendations for Western Top Temple at the 36th Technical Session and the 29th Plenary Session in December 2022, it was stated that *'It is also recommended that it ensure a method minimal restitution of the decoration is applied, scoring new blocks to ensure continuity of the decoration on the original blocks, but without making an identical copy'*.

The most controversial aspect of finishing the new supplementary materials at the Ta Nei Temple's East Gate was the treatment of the lintel and colonettes around the entrance (Figure 8.3.7). Only the damaged materials of the lintel from the western side exist, with those of the eastern side yet to be found. A few colonette fragments have been unearthed from the area around the gate, but it is unknown where they fit exactly, as they only compose a small part of the total length of the colonettes. It was decided not to reuse these fragments as structural strength was prioritised, but it was a major challenge to decide the kind of finish to use for the new colonette materials, which could not be left absent in view of structural and aesthetic integrities.

In conclusion, a decision was made to engrave a molding outline on the western colonettes, seeking to balance them with the original lintel material. The basic dimensions and patterns were based on the excavated fragments of the original material and remnants of the colonettes from the West Gate, which have an identical design fundamentally (Figure 8.3.8). As the designs of the colonettes on the West Gate differ slightly from those of the buildings constituting the Central Complex of the temple, and the patterns on the fragments found near the East Gate are the same as those at the West Gate, it is safe to assume that these fragments came from the East Gate.

The lintel was not engraved at all on the eastern side, while the colonettes were restored only to create the silhouette of a square base and an octagonal shaft without any further details. Once completed, this will not stand out as much as initially expected. It is hoped that one day, upon the discovery of the original lintel material, the façade of the East Gate can finally be recovered, following discussions on whether to put it back to its original position or make a replica by engraving the same patterns on the existing material.

Figure 8.3.6 Eastern pediment, photos from ca. 1930 (Left: EFEO_CAM08916) and after restoration (Right)

Figure 8.3.7 Lintel and colonettes after restoration (eastern and western faces)

Figure 8.3.8 A fragment of a colonette remaining at the West Gate

Chapter 9

Reassembly

9.1. Stone Repair Work

RO Sovandaroath, MOM Sophon, PRUM Sopheak, CHHAY Loeun

9.1.1. Outline of the stone repair work

Stone repair work was conducted between 5 December, 2019 and the end of December 2020 by APSARA's stone conservation team, which consisted of the following members: RO Sovandaroath, MOM Sophon, PRUM Sopheak, and CHHAY Loeun. The team examined the existing condition of the dismantled stones and completed the documentation necessary to determine the appropriate repair process for 355 stones, which is explained in detail in this chapter.

After a general observation, it was confirmed that most of the stone was decayed and/or cracked because of natural factors, such as mosses, mites, termites, and tree roots (Figures 9.1.1-9.1.3). Furthermore, the existence of abundant amounts of water, salt, and soil caused this situation to worsen.

To repair the degraded stones, the stone conservation team of APSARA followed the process cited below:

- General observation, risk assessment, and determination of repair methods
- Cleaning work (dry and wet cleaning), [355 cases] (Figure 9.1.4 and Figure 9.1.5)
- Saline removal and killing of germs and mosses, [51 cases] (Figure 9.1.6 and Figure 9.1.7)
- Reinforcement work [348 cases] (Figure 9.1.8)
- Gluing the broken stone pieces [339 cases] (Figure 9.1.9)
- Drilling and connecting large pieces using stainless steel bars [172 cases] (Figure 9.1.10)
- Filling gaps with lime mortar [328 cases] (Figure 9.1.11)
- Use of new stones to replace missing stone pieces [19 cases]

9.1.2. Stone repair process

The process of stone repair is described as follows.

Step 1: Documentation

The objects were documented to understand their degradation status and value (history, art, architecture, technique), and to assess the necessary repair work (Figure 9.1.12).

1. Study of iconography and the Khmer art history revolution, which is closely related to the object.
2. Observation of the type, quality, and constitution of the object to determine the proper repair methods.
3. Observation of previous stone processing, shaping, and carving.
4. Photographic documentation to compare the differences before and after repair, focusing on the level of degradation before repair and the implemented repairs.
5. Production of drawings of the object and mapping of the stone condition and state after previous restoration to help monitor changes in the parts after restoration and repairs.

Step 2: Risk assessment and determination of repair methods

After documentation, a risk assessment was conducted for each stone. The repair methods were examined and recorded in observation forms containing the following three points (Figures 9.1.13-9.1.15).

A. General description of the object (name, type, size, photo, style, art, etc.)

B. Degradation of the object, focusing on the decay of the object and the factors that caused degradation. Observations were made visually or using a digital microscope to identify the cause of degradation. For the East Gate restoration, 61 stones were identified to be restored. Their conditions were categorised as follows and documented in the observation forms: broken (129 fragments), missing (47), deposit (60), lichen (61), large cracks and hairline cracks < 0.1 mm (29), erosion (35), sanding (15), oxidation (1) and scaling (12).

C. Repair methods for each stone were determined based on the risk assessment, as detailed in the observation forms. All repair processes followed the ICC-Angkor recommendations.

Step 3: Cleaning treatment

The stones were cleaned with minimum intervention to preserve the temple environment.

General cleaning of the entire stone surface was performed using scalpels and spatulas (dry cleaning). All broken stones and connection surfaces were cleaned with a brush using demineralised water (wet cleaning).

The cleaning treatments were applied depending on the damage conditions of each stone. Tests were conducted prior to cleaning the original stones to avoid unexpected results.

- Cleaning deposit:

As the component stones of the East Gate collapsed long ago, most were covered by coherent and incoherent deposits including sand, clay, tree glue, root, insect nets, and stains. Coherent deposits were removed from the surface using a brush; mechanical cleaning of incoherent deposits was conducted using a scalpel.

- Disinfection:

Preventive biocide (4%) was mixed with water, applied directly to the mosses, and left for 14 days for disinfection. The stones were cleaned with a brush and demineralised water. This treatment was used only on surfaces to be glued in a later repair phase to minimise the effect on other stone surfaces.

- Poultice (compress):

After checking for the presence of salt and moss, cellulose powder (1), clay (1), Japanese paper, and demineralised water were applied to the stone surfaces to soften the deposits and absorb the soluble salt (desalination), remaining on the stones until dry before cleaning with a sealant.

As with disinfection, this treatment was used only on surfaces to be glued, and was necessary before the consolidation process.

Step 4: Consolidation and intervention treatment

The first step was pre-consolidation for fragile stones (with scaling) that required consolidation before cleaning (to avoid severe erosion). The second step was consolidation after completion of cleaning.

Some stones were decayed due to salt crystallisation and the flow of rain water, causing erosion, scaling and sanding.

Ethyl silicate (temperature 20℃ , RH 50%) was used on all gluing surfaces and drilled holes to rebind or stabilise fragile stone surfaces damaged by erosion, scaling, and sanding to ensure the resistance of the stone surface before applying glue with a syringe. Ethyl silicate can be applied once or twice depending on the stone condition; two weeks are required to rebind the stones.

- Repairing cracks:

In addition to ethyl silicate, the needle-bridge technique was used, dotting the epoxy resin (Sikadur) mixed with sandstone powder on the cracks point-by-point to reinforce them.

- Attaching small fragments:

After cleaning and disinfection of the stone surface, epoxy resin was applied point-by-point to retain moisture lost as a result of the stone porosity. Epoxy resin should be applied only to the inner sandstone surface, avoiding exposure to the environment to ensure the quality of the material.

- Attaching large fragments:

The surfaces of the connecting pieces were cleaned and consolidated. For attaching fragments that did not bear the load of the structure, the epoxy resin was applied point-by-point. For connecting large fragments that supported a large load or resisted a strong force of movement, stainless steel bars were inserted into holes filled with epoxy resin to connect broken stone pieces.

- Drilling:

First, the best location for drilling was determined. Two parallel lines were drawn on all sides to ensure correct drilling. Drilling began with smaller holes, increasing in size (6–22 mm); the hole depth was between 9 cm and 15 cm (the hole is always larger than the bar diameter). All surfaces and drilled holes were cleaned using acetone. Epoxy resin was poured into the holes until filled to remove all air, and dotted on the areas surrounding the holes to provide a larger gluing surface.

Step 5: Filling gaps and colouring

After connecting the broken stone pieces, some original stone pieces were missing; new stones were required to fill these gaps. For areas with small or thin layers of stones missing or cracks in the layers, adhesives and reinforcement were used to prevent further cracking. Mortar pointing was conducted.

- Filling with mortar:

Mortar was used to fill large cracks, small breaks at the corners of sandstone blocks, and gaps between connecting stones. The mortar was prepared by mixing two scales of sand, one scale of sandstone powder, and lime putty or slaked lime. The grain size of the original sandstone was coloured to match the mortar in appearance. The hardness of the mortar was less than that of the sandstone, ensuring reduced moisture in the cracks between the stones for conservation.

- Filling with new stone:

To repair load-bearing sandstone with large broken parts, fragments of new sandstone were used. The sandstone material was selected to be similar in colour to the original stone. Gluing used the technique described in step 4.

To finish the newly supplemented sandstone, carving was conducted, following the original carvings but only shaping the outline of the original.

- Colouring:

For mismatched colouring between the mortar and original sandstone, a colouring method was used for a natural appearance until the mortar surface was weathered to match the sandstone. Oil and ethyl silicate for outdoor use were applied to retouch the mortar colour.

Step 6: Final report and monitoring

After completion of the repair work, a technical report was compiled. Regular maintenance will be performed three months after completion and after one or three years, depending on the condition of the building.

Figure 9.1.1 Examples of stone damage

Figure 9.1.2 Examples of stone decays

Figure 9.1.3　Examples of stone cracks

Figure 9.1.4　Dry cleaning process

Figure 9.1.5　Wet cleaning process

Figure 9.1.6　Killing germs and mosses

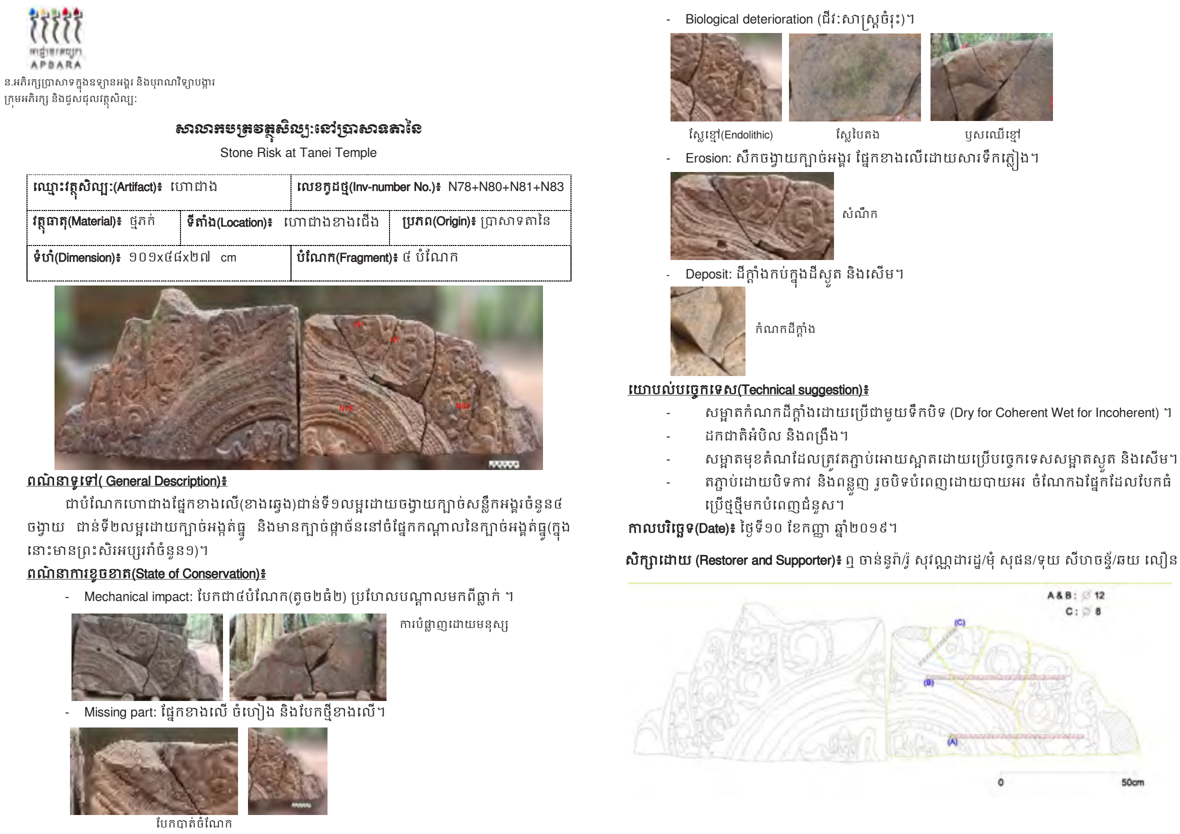
Figure 9.1.7　Removal of saline

Figure 9.1.8　Stone reinforcement process

Figure 9.1.9　Use of adhesives for connecting the broken stone pieces

Figure 9.1.10　Drilling and gluing process

Figure 9.1.11 Lime mortar used for filling the gaps and cracks



ន.អភិរក្សប្រាសាទក្នុងឧទ្យានអង្គរ និងបុរាណវិទ្យាបង្ការ
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សាលាកបត្រវត្ថុសិល្បៈនៅប្រាសាទតានៃ

Stone Risk at Tanei Temple

ឈ្មោះវត្ថុសិល្បៈ(Artifact)៖ ហោជាង		**លេខកូដថ្ម(Inv-number No.)៖** N78+N80+N81+N83
វត្ថុធាតុ(Material)៖ ថ្មភក់	**ទីតាំង(Location)៖** ហោជាងខាងជើង	**ប្រភព(Origin)៖** ប្រាសាទតានៃ
ទំហំ(Dimension)៖ ១០១x៤៨x២៧ cm		**បំណែក(Fragment)៖** ៤ បំណែក

ពណ៌នាទូទៅ(General Description)៖

ជាបំណែកហោជាងផ្នែកខាងលើ(ខាងឆ្វេង)ជាន់ទី១លម្អដោយចង្វាយក្បាច់សន្លឹកអង្គរចំនួន៤ចង្វាយ ជាន់ទី២លម្អដោយក្បាច់អង្កត់ធ្នូ និងមានក្បាច់ផ្កាច័ននៅចំផ្នែកកណ្តាលនៃក្បាច់អង្កត់ធ្នូ(ក្នុងនោះមានព្រះសិរអប្សររាំចំនួន១)។

ពណ៌នាការខូចខាត(State of Conservation)៖

- Mechanical impact: បែកជា៤បំណែក(តូច២ធំ២) ប្រហែលបណ្តាលមកពីធ្លាក់ ។

ការបំផ្លាញដោយមនុស្ស

- Missing part: ផ្នែកខាងលើ ចំហៀង និងបែកថ្មីខាងលើ។

បែកបាត់ចំណែក

- Biological deterioration (ជីវៈសាស្ត្រចំរុះ)។

ស្លែខ្មៅ(Endolithic) ស្លែបៃតង ឫសឈើខ្មៅ

- Erosion: សឹកចង្វាយក្បាច់អង្គរ ផ្នែកខាងលើដោយសារទឹកភ្លៀង។

សំណឹក

- Deposit: ដីក្តាំងកប់ក្នុងដីស្ងួត និងសើម។

កំណកដីក្តាំង

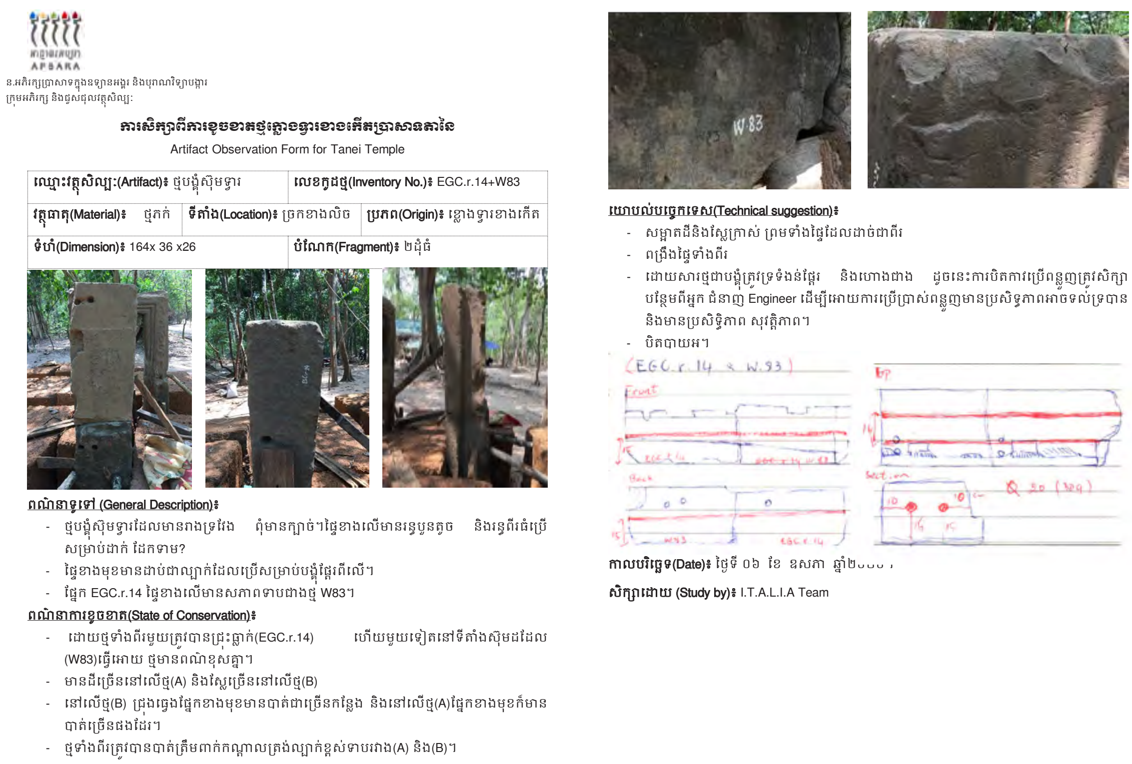
យោបល់បច្ចេកទេស(Technical suggestion)៖

- សម្អាតកំណកដីក្តាំងដោយប្រើជាមួយទឹកបិទ (Dry for Coherent Wet for Incoherent) ។
- ដកជាតិអំបិល និងពង្រឹង។
- សម្អាតមុខតំណដែលត្រូវតភ្ជាប់អោយស្អាតដោយប្រើបច្ចេកទេសសម្អាតស្ងួត និងសើម។
- តភ្ជាប់ដោយបិទការ និងពន្លួញ រួចបិទបំពេញដោយបាយអរ ចំណែកឯផ្នែកដែលបែកធំប្រើថ្មថ្មីមកបំពេញជំនួស។

កាលបរិច្ឆេទ(Date)៖ ថ្ងៃទី១០ ខែកញ្ញា ឆ្នាំ២០១៩។

សិក្សាដោយ (Restorer and Supporter)៖ ព្ ចាន់នូវ៉ា/រ៉ូ សុវណ្ណដារដ្ឋ/មុំ សុផន/ទុយ សីហចន្ទ័/ឆយ លឿន

Figure 9.1.12 Examples of observation sheets for stone repair work



ន.អភិរក្សប្រាសាទក្នុងឧទ្យានអង្គរ និងបុរាណវិទ្យាបង្ការ
ក្រុមអភិរក្ស និងជួសជុលវត្ថុសិល្បៈ

ការសិក្សាពីការខូចខាតថ្មគ្រោងទ្វារខាងកើតប្រាសាទតានៃ

Artifact Observation Form for Tanei Temple

ឈ្មោះវត្ថុសិល្បៈ(Artifact)៖ ថ្មបង្គុំស៊ុមទ្វារ		**លេខកូដថ្ម(Inventory No.)៖** EGC.r.14+W83
វត្ថុធាតុ(Material)៖ ថ្មភក់	**ទីតាំង(Location)៖** ច្រកខាងលិច	**ប្រភព(Origin)៖** ខ្លោងទ្វារខាងកើត
ទំហំ(Dimension)៖ 164x 36 x26		**បំណែក(Fragment)៖** ២ដុំធំ

ពណ៌នាទូទៅ (General Description)៖

- ថ្មបង្គុំស៊ុមទ្វារដែលមានរាងទ្រវែង ពុំមានក្បាច់។ផ្ទៃខាងលើមានរន្ធបួនតូច និងរន្ធពីរធំប្រើសម្រាប់ដាក់ ដែកទាម?
- ផ្ទៃខាងមុខមានដាប់ជាល្បាក់ដែលប្រើសម្រាប់បង្គុំផ្តែរពីលើ។
- ផ្នែក EGC.r.14 ផ្ទៃខាងលើមានសភាពទាបជាងថ្ម W83។

ពណ៌នាការខូចខាត(State of Conservation)៖

- ដោយថ្មទាំងពីរមួយត្រូវបានជ្រុះធ្លាក់(EGC.r.14) ហើយមួយទៀតនៅទីតាំងស៊ុមដដែល (W83)ធ្វើអោយ ថ្មមានពណ៌ខុសគ្នា។
- មានដីច្រើននៅលើថ្ម(A) និងស្លែច្រើននៅលើថ្ម(B)
- នៅលើថ្ម(B) ជ្រុងឆ្វេងផ្នែកខាងមុខមានបាត់ជាច្រើនកន្លែង និងនៅលើថ្ម(A)ផ្នែកខាងមុខក៏មានបាត់ច្រើនផងដែរ។
- ថ្មទាំងពីរត្រូវបានបាត់ត្រឹមពាក់កណ្តាលត្រង់ល្បាក់ខ្ពស់ទាបរវាង(A) និង(B)។

យោបល់បច្ចេកទេស(Technical suggestion)៖

- សម្អាតដីនិងស្លែក្រាស់ ព្រមទាំងផ្ទៃដែលដាច់ជាពីរ
- ពង្រឹងផ្ទៃទាំងពីរ
- ដោយសារថ្មជាបង្គុំត្រូវទ្រទំងន់ផ្តែរ និងហោងជាង ដូចនេះការបិតការប្រើពន្លួញត្រូវសិក្សាបន្ថែមពីអ្នក ជំនាញ Engineer ដើម្បីអោយការប្រើប្រាស់ពន្លួញមានប្រសិទ្ធភាពអាចទល់ទ្របាន និងមានប្រសិទ្ធិភាព សុវត្ថិភាព។
- បិតបាយអ។

កាលបរិច្ឆេទ(Date)៖ ថ្ងៃទី ០៦ ខែ ឧសភា ឆ្នាំ២...

សិក្សាដោយ (Study by)៖ I.T.A.L.I.A Team

Figure 9.1.13 Examples of observation sheets for stone repair work

ន.អភិរក្សប្រាសាទក្នុងឧទ្យានអង្គរ និងបុរាណវិទ្យាបង្ការ
ក្រុមអភិរក្ស និងជួសជុលវត្ថុសិល្បៈ

ការសិក្សាពីការខូចខាតថ្មភ្លោងទ្វាខាងកើតប្រាសាទតានៃ

Artifact Observation Form for Tanei Temple

ឈ្មោះវត្ថុសិល្បៈ(Artifact)៖ ថ្មហោជាង?		**លេខកូដថ្ម(Inventory No.)៖** S 25.1, 25.2, 25.3 & 25.4
វត្ថុធាតុ(Material)៖ ថ្មភក់	**ទីតាំង(Location)៖** S	**ប្រភព(Origin)៖** ច្រកចូលកើត
ទំហំ(Dimension)៖ 114 x 54 x 34cm		**បំណែក(Fragment)៖** 8បំណែក (ធំ4)

ពណ៌នាទូទៅ (General Description)៖

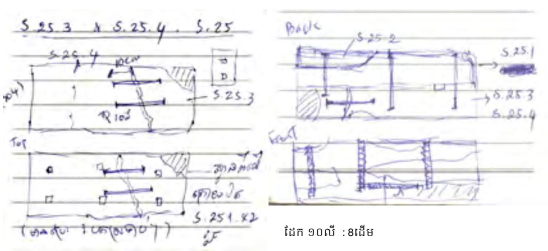
- ថ្មបង្កុំហោជាងដែលផ្ទៃខាងមុខឃើញមានដាប់ក្បាច់ចម្លាក់រូបទេពត្រឹមដងខ្លួន និងមានក្បាច់អង្កត់ធ្នូផងដែរ
- ផ្ទៃខាងលើជ្រុងខាងស្តាំមានដាប់ល្បាក់សម្រាប់ការងាររៀបថ្ម
- ផ្ទៃខាងក្រោយមានសភាពគ្រើម និងផ្ទៃដំទៃមានសភាពរាបស្មើ

ពណ៌នាការខូចខាត(State of Conservation)៖

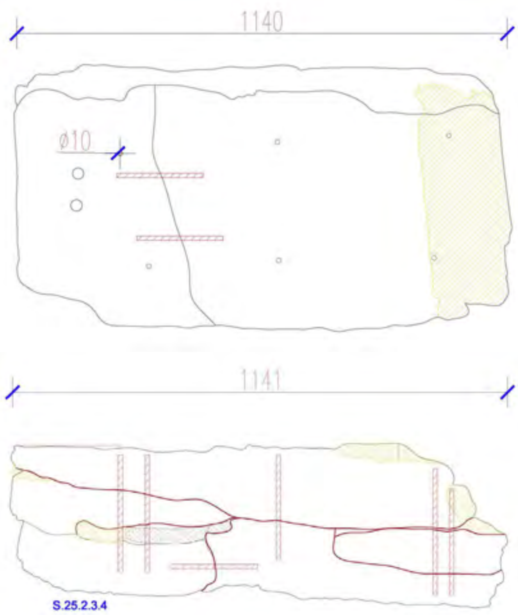
- ផ្ទៃថ្មទាំងមូលត្រូវគ្របដោយដី ស្លែ
- ថ្មមានសភាពបែកធ្ងន់ធ្ងរជាច្រើនបំណែក និងមានបែកបាត់ផងដែរ
- សាច់ថ្មមានសភាពប្រេះជាស្រទាប់ និងមានលក្ខណៈពុកផុយ

យោបល់បច្ចេកទេស(Technical suggestion)៖

- សម្អាតទូទៅ
- ពង្រឹងទីតាំងពុកផុយ
- បិតភ្ជាប់បំណែកតូចៗចូលមុន រួចបិតភ្ជាប់បំណែ S.25.2, S.25.3 & S.25.4 ដោយប្រពន្លួញ
- បិតភ្ជាប់បំណែកខាងលើជាមួយបំណែក S.25.1ដោយប្រើពន្លួញផងដែរ
- បិតបំពេញបាយអ និងប្រើថ្មថ្មីនៅទីតាំងដែលបែកបាត់



ដែក ១០លី :8ដើម



កាលបរិច្ឆេទ(Date)៖ ថ្ងៃទី ២១ ខែ ឧសភា ឆ្នាំ២០២០។

សិក្សាដោយ (Study by)៖ I.T.A.L.I.A Team

Figure 9.1.14 Examples of observation sheets for stone repair work

ន.អភិរក្សប្រាសាទក្នុងឧទ្យានអង្គរ និងបុរាណវិទ្យាបង្ការ
ក្រុមអភិរក្ស និងជួសជុលវត្ថុសិល្បៈ

ការសិក្សាពីការខូចខាតថ្មក្លោងទ្វារខាងកើតប្រាសាទតានៃ

Artifact Observation Form for Tanei Temple

ឈ្មោះវត្ថុសិល្បៈ(Artifact)៖ ស៊ុមទ្វារ	**លេខកូដថ្ម(Inventory No.)៖** EGC.1/16.1 &1/16.2	
វត្ថុធាតុ(Material)៖ ថ្មភក់	**ទីតាំង(Location)៖** E	**ប្រភព(Origin)៖** ច្រកចូលកើត
ទំហំ(Dimension)៖ 170 x 40 x18 cm	**បំណែក(Fragment)៖** ២ធំ	

ពណ៌នាទូទៅ (General Description)៖

- ថ្មស៊ុមទ្វារដែលមានដាប់ថ្នាក់ៗជាក្បាច់នៅផ្ទៃខាងមុខ
- ជ្រុងខាងស្តាំ និងខាងឆ្វេងមានដាប់លយសម្រាប់ភ្ជាប់ទៅស៊ុមបញ្ឈរ(ខាងស្តាំតូចជាង)
- មានតួនាទីទ្រទំងន់ហោជាង និងផ្តែរ

ពណ៌នាការខូចខាត(State of Conservation)៖

- បែកជាពីរបំណែកធំត្រង់ពាក់កណ្តាល
- មានបាត់ច្រើនកន្លែងនៅជ្រុងខាងឆ្វេង
- មានស្នាមប្រេះជាច្រើន(Hair Crack)
- មានស្លែនៅផ្ទៃខាងមុខ និងខាងក្នុង

យោបល់បច្ចេកទេស(Technical suggestion)៖

- សម្អាតដី និងស្លែចេញ
- ដកអំបិល
- ពង្រឹងកន្លែងពុកផុយ និងស្នាមប្រេះ
- បិតភ្ជាបបំណែកទាំងពីរដោយប្រើពន្លួញ ស្វានទម្លុះ ដោយប្រើពន្លួញ ២០លី ២ដើម
- បិតបំពេញបាយអ

កាលបរិច្ឆេទ(Date)៖ ថ្ងៃទី ០៥ ខែ មេសា ឆ្នាំ២០២០។

សិក្សាដោយ (Study by)៖ I.T.A.L.I.A Team

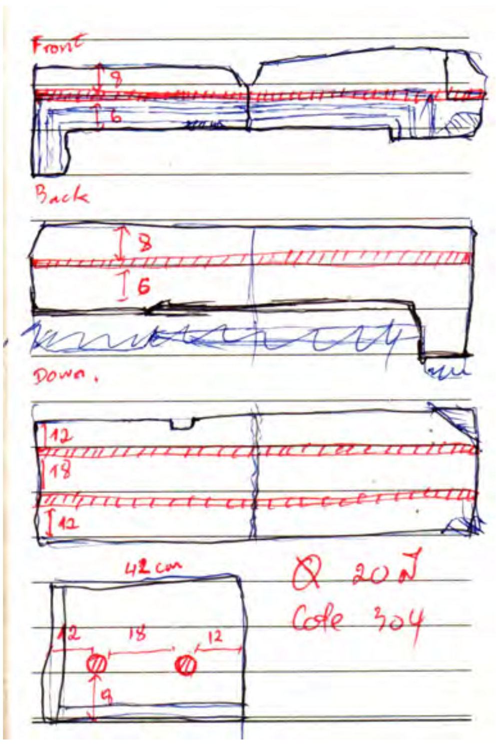


Figure 9.1.15 Examples of observation sheets for stone repair work

Table 9.1.1 Example of the documentation on risk and repair solution of each damaged stone

N°	Stone Code number	Fragement	Dimention (cm)	Type of Risk									Solution						
				Broken	Missing	Deposit	Bio	Crack	Erosion	Sanding	Scaling	Oxidation	Cleaning	Desalization	Consolidate	Glueing	Conecting by Stell or Fiber	Filling Motar	Filling New stone
1	N 78,N81,N83,N83	2	101*48*27	✓	✓	✓	✓		✓				✓	✓	✓	✓	✓	✓	✓
2	S 25.1,.2,.3,.4	8	114*54*34	✓	✓	✓	✓	✓		✓	✓		✓		✓	✓	✓	✓	✓
3	E 1	2	55*28*67	✓	✓	✓	✓		✓				✓		✓	✓		✓	
4	E 6	2	72*32*37	✓	✓	✓	✓		✓				✓		✓		✓		
5	E 7	1	70*44*20	✓	✓	✓	✓	✓	✓		✓		✓		✓	✓	✓	✓	
6	E 12	2	93*29*33	✓	✓	✓	✓	✓	✓				✓		✓	✓	✓	✓	
7	E 17	1	80*40*17		✓	✓	✓	✓					✓		✓	✓			
8	E 18-1 & E18-5	5	52*24*28	✓	✓	✓	✓	✓	✓				✓		✓	✓	✓	✓	
9	ED 8/1.1,ED 8/1.2 &	3	?	✓		✓	✓	✓	✓		✓		✓		✓	✓	✓	✓	
10	EDF 1.1&EDF 1.2	9	183*40*19	✓		✓	✓		✓		✓		✓	✓	✓	✓	✓	✓	
11	EGC.2?.3 & NE.4.3	2	116*40*28	✓	✓	✓	✓	✓				✓	✓		✓	✓	✓	✓	✓
12	EGC.3	2	?	✓	✓	✓	✓	✓			✓	✓	✓		✓	✓	✓	✓	✓
13	EGC.2?.4.1.2.3.4	13	105*50*25	✓		✓	✓			✓	✓		✓		✓	✓	✓	✓	
14	EGC.2?.7.1.2	2	105*39*24	✓	✓	✓	✓			✓	✓		✓		✓	✓	✓	✓	
15	EGC.2?.9	3	91*47*26	✓	✓	✓	✓	✓		✓	✓		✓		✓	✓	✓	✓	
16	EGC.2?.10	2	111*49*30	✓	✓	✓	✓				✓		✓		✓	✓		✓	
17	EGC.2?.11, 12	2	100*41*24	✓	✓	✓							✓		✓	✓	✓		
18	EGC. 12	2	193*41*18.5	✓	✓	✓	✓	✓		✓	✓		✓		✓	✓	✓		
19	EGC.2?.24 &E.2	4	109*39*26	✓	✓	✓	✓			✓	✓		✓		✓	✓	✓	✓	✓
20	EGC.2?.14 & W83	2	164*36*26	✓	✓	✓	✓		✓		✓		✓		✓	✓	✓	✓	
21	EGC.2?.16.1,.2	2	170*40*18	✓	✓	✓	✓	✓					✓	✓	✓		✓	✓	
22	EGC.2?.19.18.23	5	95*41*37	✓	✓	✓	✓		✓		✓	✓	✓		✓	✓	✓	✓	
23	EGC.2?.24.1.2	4	110*53*26	✓	✓	✓	✓	✓					✓		✓	✓	✓	✓	
24	EGC.2?.27 & EGC.2?	3	113*47*30	✓	✓	✓	✓	✓			✓	✓	✓		✓	✓	✓	✓	
25	EGC.2?.28 &S27	3	115*44*19	✓	✓	✓	✓				✓	✓	✓		✓	✓	✓	✓	
26	EGC.2?.14 EGC.2?.20	2	90*37.5*23	✓	✓	✓	✓	✓					✓		✓		✓	✓	
27	EP.1	2	103*46*34	✓		✓	✓			✓	✓		✓		✓	✓	✓	✓	
28	EP 3/10.1, 3/10.2	2	52*48*27	✓		✓	✓		✓				✓		✓	✓		✓	
29	EP.2.1 & EP.2.2	3	93*42*30	✓	✓	✓	✓	✓	✓		✓		✓		✓	✓	✓	✓	
30	EP 2/1	3	?	✓		✓	✓	✓	✓		✓		✓		✓	✓	✓	✓	
31	EP 2/5.1, EP 2/5.2 &	3	?	✓	✓	✓	✓	✓	✓		✓		✓		✓	✓	✓	✓	
32	EP 7/1.1.2	7	170*44*29	✓	✓	✓	✓		✓				✓		✓	✓	✓		
33	EP 8/1	3	177*41*28	✓	✓	✓	✓	✓		✓	✓		✓		✓	✓	✓		
34	ER.2.1	4	193*40*34	✓	✓	✓	✓			✓	✓		✓		✓	✓		✓	
35	ER.4	3	195*45*31	✓	✓	✓	✓		✓				✓		✓	✓		✓	

Table 9.1.2 Material and equipment list

1	Japanese Paper
2	Cellulose Powder
3	Sepiolite/Clay Powder
4	Ethyl Silicate
5	Biocide (Preventol)
6	Acetone
7	Sand
8	Sandstone Powder
9	Epoxy Resin (Sikadur)
10	Demineralize water
11	Water Spray
12	Plastic Bowl
13	Spatula

14	Tooth Brush
15	Brush
16	Bamboo Stick
17	Container
18	Spoon
19	Cotton
20	Gloves
21	Mask
22	Ziploc Bag
23	White Plastic and Tent
24	Pen, Pencil, Correction pen, Ruler
25	Chalk Line Tool

26	Metter
27	Level
28	Helmet
29	Scalpel
30	Plastic Glass
31	Sponge
32	Syringe
33	Stainless Steel bar (304)
34	Blower Motor
35	Cutting Motor
36	Drilling Motor
37	Drilling Motor (HILTI) DD120

9.2. Reassembly Work

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This section describes the details of the reassembly process, whereas Section 8.3 explains the restoration policy and method.

9.2.1. Outline of reassembly

The reassembly process was carried out as follows (Figures 9.2.1-9.2.24).

From April to May 2020, the repair of substrate laterite layer in the east wing of the base structure and the reassembly of the exterior sandstones were carried out. At the beginning of June, reassembly of the exterior sandstones of the base structure was completed after several readjustments to avoid creating any gaps between the stones. Accordingly, the damaged substrate laterite blocks were replaced by new laterites in the western wing of the base structure. In the middle of June, the reassembly of the floor sandstones began; however, a gap was found between the floor and base structure sandstones in the northwest, and the part was dismantled again until Layer 20, and the trial assembly were repeated. After several readjustments, the exterior sandstones of the base structure were constructed in mid-July. The wall was trial-assembled up to two layers from the floor level to check its precision, and then the floor sandstones were repaved and surrounded by the wall. From August, the wall reassembly started in parallel with the paving of the floor sandstones, and by the end of August, the wall was assembled up to its middle height. From the beginning of September, the west opening frame began to be reassembled, whereas the wall reassembly continued. In early October, the assembly of the eastern opening frame began, and rebuilding was completed up to the colonettes and lintels of both the east and west entrances. Rebuilding of the pediment and roof followed, and by the end of November, the roof was approximately completed up to the top. The reassembly of the finial started in December and was approximately completed by mid-December, while the carving finishing was completed at the beginning of January.

Because of the spreading of COVID-19 in April 2020, TOBUNKEN staff members were not able to work on-site together with APSARA, and a series of online meetings were organised between APSARA and TOBUNKEN to share the site situation and discuss how to proceed with restoration work on the site. The actual restoration methods were discussed and determined in online meetings, and APSARA proceeded with the work on-site.

In January 2022, after lifting the travel restrictions, TOBUNKEN staff members visited the site and confirmed the status of the reassembly. Final retouch work was conducted during an on-site meeting between APSARA and TOBUNKEN. The repair of the small breaks of sandstone and curving finishing were carried out separately in June and November 2022, and the restoration work of the East Gate was finally completed.

Figure 9.2.1 Work progress in March, 2020 (Northeast view)

Figure 9.2.2 Work progress in March, 2020 (Southeast view)

Figure 9.2.3 Work progress in March, 2020 (Southwest view)

Figure 9.2.4 Work progress in March, 2020 (Northwest view)

Figure 9.2.5 Work progress in April, 2020 (Northeast view)

Figure 9.2.6 Work progress in April, 2020 (Southeast view)

Figure 9.2.7 Work progress in April, 2020 (Southwest view)

Figure 9.2.8 Work progress in April, 2020 (Northwest view)

Figure 9.2.9 Work progress in May, 2020 (North view)

Figure 9.2.10 Work progress in May, 2020 (Southeast view)

Figure 9.2.11 Work progress in May, 2020 (Southwest view)

Figure 9.2.12 Work progress in May, 2020 (Northwest view)


Figure 9.2.13 Work progress in September, 2020 (Northeast view)


Figure 9.2.14 Work progress in September, 2020 (Southeast view)


Figure 9.2.15 Work progress in September, 2020 (Southwest view)


Figure 9.2.16 Work progress in September, 2020 (Northwest view)


Figure 9.2.17 Work progress in October, 2020 (Northeast view)


Figure 9.2.18 Work progress in October, 2020 (Southeast view)

Figure 9.2.19 Work progress in October, 2020 (Southwest view)

Figure 9.2.20 Work progress in October, 2020 (Northwest view)

Figure 9.2.21 Work progress in November, 2020 (Northeast view)

Figure 9.2.22 Work progress in November, 2020 (Southeast view)

Figure 9.2.23 Work progress in November, 2020 (Southwest view)

Figure 9.2.24 Work progress in November, 2020 (Northwest view)

9.2.2. Reassembly process

(1) Reassembly of the base structure

The basic policy for the dismantlement of the base structure was decided such that only the exterior sandstones would be dismantled and reassembled, while the substrate laterite and compacted soil layers within the base were left untouched. Following this policy, the exterior sandstones were dismantled layer by layer; however, the two or three exterior sandstones in contact with the southern and northern Outer Enclosures, which had relatively little displacement, were not dismantled below Layer 18 and were used as benchmarks for rebuilding. The laterite rows on the lowest layer (Layer 21) were not dismantled and remained intact.

However, the dismantlement of the exterior and floor sandstones revealed deterioration of the substrate laterite.

- Some parts of the substrate laterite blocks, which work as molds for compacted soil within the base, were absent from the original construction, and there was direct contact between the inner compacted soil and exterior sandstones. The inner soil partially flowed out of these areas (Figure 9.2.26).
- Tree roots penetrated the base structure and pushed out some substrate laterite blocks (Figures 9.2.27-9.2.29).
- The fine tree roots penetrated the fine holes in the substrate laterite blocks and destroyed them.
- Some of the substrate laterite blocks of the floor were thin and slightly deformed by the superstructure loads.

Measures to address this problem were discussed between APSARA and TOBUNKEN during online meetings in April and May 2020. Based on the material and structural analysis conducted in April and from the perspective of geotechnical and structural engineering, it was assumed that the base itself had been sufficiently consolidated by years of consolidation settlement, and that dismantling the laterite and internal soil layers would cause the base itself to lose strength. Therefore, to prevent future deterioration, it was decided not to dismantle the substrate laterite and internal soil layers, replace the deteriorated parts with new materials, or insert new materials, as described in Section 8.3.

Based on this policy, the reassembly of base structure was conducted as follows (Figure 9.2.25).

1. Absence of laterite blocks in the Base

The substrate laterite blocks were irregularly absent in the southern half of the eastern wing of the base structure and were filled with compacted soil. This was assumed to cause partial erosion of the infill soil, and its irregular formation was considered to affect the stability of the superstructure because the part was located below the east entrance where the load of the upper structure was concentrated. Therefore, the infill soil in the absence of laterite and the surrounding laterite base were replaced and rebuilt with new laterite blocks. The laterite blocks of the northern half of the east wing were heavily deteriorated and had to be replaced with new laterite blocks (Figures 9.2.32-9.2.37).

2. Base laterite pushed out by tree root intrusion

Starting from the reference stones in the northern and southern exterior sandstones as a benchmark, the reassembly of the exterior sandstones in Layer 20 began. At this stage of reassembly, problems arose on the east and west sides of the north wing, where tree root intrusion pushed out the substrate laterite approximately 1.5 cm (ranging between 1 and 2 cm), which interfered with the exterior sandstone and prevented them from being delivered in their original position. Thus, two solutions were discussed in the online meeting between APSARA and TOBUNKEN: (a) disassembling the laterite materials in the displaced part and returning them to their original positions, or (b) cutting out the necessary parts in the outer edge of the laterites without changing their existing positions. Because the stability of the existing base structure could be estimated to a considerable extent by engineering calculations, and laterite blocks itself turned into fragile conditions, and as mentioned earlier, there was a risk of loosening the compressed internal soil layer if the partial dismantling was conducted. it was finally decided that the latter solution (b) should be implemented (Figure 9.2.50).

3. Lateral deterioration

During dismantling, it was confirmed that the laterite blocks were thin and small, and had deteriorated in the area below the west entrance. Some were broken into pieces by penetration of the tiny tree roots inside the fine holes in the laterite blocks. In addition, four layers of laterite exist on the northern side of the west entrance, whereas only three layers exist in some areas on the southern side, causing foundation instability. Some areas in the foundation, which consisted of soil layers combined with laterite blocks, were in poor condition.

Therefore, it was decided that the base laterite would be replaced with new laterite blocks in the western wing area. The damaged laterite blocks below the wall structure that received a static load were replaced with new laterite blocks that were larger than the original for structural reinforcement. The stability of the new laterite was secured by applying lime mortar to fill the gap between the surrounding compacted soil or sandstones and the new laterite blocks (Figures 9.2.38-9.2.43). In contrast, the substrate laterites and compacted soil below the floor pavement, which did not bear the upper loads, were maintained in the original condition, even though they had deteriorated somewhat.

On the north side of the west wing, where the laterite directly below the wall had a complicated shape, it was difficult to insert laterite of the same shape when replacing it with new laterite; therefore, new rectangular laterite and sandstone pieces were inserted to adjust the gap (Figures 9.2.46-9.2.47).

4. Reassembly of base structure exterior sandstones

The dismantled exterior sandstones began to reassemble sequentially from the northern and southern benchmarks. However, a difference in height occurred at the point where the stone rows on both sides met, and a misalignment was particularly noticeable near the centre of the eastern wing.

The northern side of the base structure was previously confirmed to be in relatively good condition; however, during the dismantlement of exterior sandstones, it was found that the tree roots penetrated the base structure, and the significant deterioration of the substrate laterite on the east and west sides of the north wing had caused problems, resulting in gaps between the stones. Therefore, the sandstone rows that had been used as benchmarks on the north side had to be dismantled and reassembled, whereas the reference stones on the south side were untouched (Figure 9.2.48). Lime mortar (mix ratio=fine sand: slake lime: sandstone powder: brick powder = 3:2:2:1) was compacted on the top surface of the laterite rows of Layer 21 to adjust for the unevenness of the exterior sandstones in Layer 20.

It was difficult to reassemble sandstones that had already been precisely shaped at the time of the original construction. To adjust them, there was an uneven adjusting layer at some parts of the base structure, in this case, the East Gate, between layers 21-20 and layers 18-17 (Figure 9.2.44). Lime mortar was applied as an unevenness-adjusting material between 21-20, since the layer was located under the original ground surface during the Angkor period, and a lower risk of lime mortar outflow was assumed. Level adjustment was also necessary between layers 18-17, which was the boundary between the base structure and superstructure, where the upper load bears the base structure. For the unevenness-adjusting material, lead plates were applied when the gap was less than 10 mm, and sandstone fragments were used when the gap was larger.

To verify the accuracy of the reassembly, a metal linear scale with a thickness of 1 mm was used. When the gap between the sandstones was sufficiently large to allow insertion into the sandstone joints, the readjustment of sandstones and surrounding stones, dismantling, reassembling, and adjusting the unevenness were repeated until the exterior sandstones were piled without gaps (Figures 9.2.51-9.2.53).

5. Preventive measures against exterior sandstone movement

To prevent outward movement of the exterior sandstones in relation to each other, stainless-steel clamps were installed at the corners of the base structure (Figure 9.2.55).

6. Absence of peripheral stones

Some corner sandstones of the base structure were absent before restoration and were not found during the investigation of scattered stones in the surrounding area (Figure 9.2.45). As the missing stones could have led to lateral displacement of the base, new-material sandstones were inserted with the estimated original size.

Besides that, there was a place that two laterite blocks were inserted in an irregular form at the southwest corner of the west wing. However, traces on the upper surface of the sandstone immediately below them indicate that a stone of a different shape was placed in the original construction, and the two laterite stones were reinstalled in a later period (see Section 5.2). Although the period of this replacement is unknown, the laterite blocks were considered to be material pertaining to the structure of the main causeway between the East Gate and Cruciform Terrace, which does not currently exist, and its existence in the past has been discussed to date. Although it was desirable to retain the existing material in situ, these two laterite blocks were fragile and broke down into pieces during dismantlement.

Considering the stability of the exterior sandstones of the base structure, a new sandstone was installed temporarily instead of the two existing laterite blocks during restoration, which was formed in the size that was assumed from the trace of the stone below.

While these two laterite blocks could be considered one of the few pieces of physical evidence of the existence of the causeway structure, this replacement should be reexamined when future investigations reveal the relationship between the East Gate and the causeway.

7. Backfilling the area surrounding the base structure

The area surrounding the base structure, which consisted of a mixture of soil and sandstone chips, was dug down to the deepest layer for reassembly.

After the completion of the rebuilding of the base structure, the surrounding area was backfilled with the original soil, and a new filling with the same composition as the original material was added when necessary, and then compacted with a wooden stick.

(2) Floor

After the rebuilding of the exterior sandstone at the base was completed, reassembly of the sandstone at the floor level was initiated. When the sandstone was laid from the outer edge, a 7 cm gap was formed between the sandstones in the northwest of the west wing (Figure 9.2.54). Thus, the exterior sandstones were dismantled again to Layer 20 northwest of the base structure. Readjustment was repeated by dismantling and reassembling this part, and finally, all the stones of the base structure were settled in place without gaps. Accordingly, the walls of the first two or three layers were assembled before the floor pavement to ensure that the wall body could be constructed without distortion. The work commenced by laying floor sandstones inside the wall. As described in Section 5.2, an uneven adjusting material, which is a mixture of soil, laterite chips, and sandstone chips, was applied originally between the substrate laterite and floor sandstones when placing the floor stone. This material was removed during dismantlement, and during reassembly, lime mortar was used as a level-adjusting material, which provided more stable strength (Figures 9.2.56-9.2.57).

(3) Wall

Wall reassembly was conducted in parallel by paving floor stones (Figures 9.2.58-9.2.59). The two crane trucks operated simultaneously to pile up the repaired sandstone material in two different directions (Figure 9.2.60).

A few of the sandstones that made up the wall collapsed before restoration, and all the missing stones were found among the scattered stones and could be reused. Thus, the entire wall structure was assembled using the original sandstones.

1. Wall structural reinforcement

To prevent the horizontal shifting of the wall sandstones, clamps were used as structural reinforcement, basically at the corner of the cruciform plan in every three layers, which might risk collapse if deformation of the superstructure occurs in the future (Figures 9.2.62-9.2.63). After confirming that the sandstones fit together without gaps, a groove was cut at the top edge of the sandstone using a handheld circular saw, holes were drilled vertically at both ends of the groove, and clamps were inserted. One clamp was inserted when the contact line between the stones to be joined was less than 40 cm, and two clamps were inserted when the contact line was more than 40 cm. The length of the clamps was approximately 25 cm and the depth at both ends was approximately 4 cm.

2. Cavity on inner wall of south side of west wing

There is a relatively large cavity on the inner wall on the south side of the west wing, as described in Section 3.2. It is not known whether this void was artificial or of any significance; however, in this restoration, the cavity was left as it was.

(4) Entrance

When the wall assembly was completed at the middle height, the entrance assembly was started.

1. Opening frame

The damaged opening frame members were repaired before reassembly (see Section 9.1 for details) (Figures 9.2.64-9.2.65, and 9.2.74). Vertical frame members were erected along the wall body, and the upper member was placed on it. Grooved engravings carved on the outside of the opening frame were used as the horizontal and vertical guides. A transparent hose filled with water was used to determine the horizontal direction (Figure 9.2.66).

2. Colonette

All the colonettes were missing at both the east and west entrances, and only a few fragments were found among the scattered stones. As mentioned in Section 5.2, it is highly likely that the original colonette of the East Gate was made by joining two or more pieces of sandstone, and the joint on the bottom side was different at each location at the east and west entrances. In the reassembly, the following two proposals were considered in discussions between APSARA and TOBUNKEN: (i) A stainless-steel pipe inserted into the colonette bore the load, and sandstone was attached around the steel pipes as an exterior to create the shape of the colonette. (ii) The colonette was made from a single or multiple sandstones.

The colonette uses the stratigraphic direction of the sandstone material vertically. Therefore, if the vertical load is excessive, there are many cases of the stone itself cracking, which can easily become a structural weakness. The TOBUNKEN side proposed the insertion of steel pipe reinforcement, emphasizing structural safety, whereas APSARA proposed reconstruction using sandstone material, thereby emphasizing the original construction method.

As a result of these discussions, it was decided that the colonette would be restored with a single sandstone material, considering the balance between the assumed original construction methods and structural safety. Architectural investigations have shown that the colonette of the East Gate was likely to have been originally made from two or more pieces of sandstone. However, because the position of the joints was unknown, a proposal to build a colonette from a single piece of sandstone was adopted. Stainless-steel clamps were installed to prevent outward movement of stones connecting the colonette and pilasters, lintel, upper opening frame, and adjacent wall (Figure 9.2.67).

In cases where there were traces of mortise holes on the upper surface of the sandstone, where the legs of the colonette met, mortises were also made on the legs of the new colonette (Figure 9.2.68). However, the colonette footing on the south side of the east entrance has been irregularly integrated with the stone of the pilaster footing since its initial construction. Because of the deterioration of this stone, the colonette could not be placed on it stably; therefore, only the part below the colonette was cut away, and a new stone of the height estimated from the traces was inserted as the base of this colonette.

The colonette on the north side of the west entrance did not have any traces of mortise at the bottom or top, but had traces of separate member at the bottom of the colonette. Thus, a new sandstone was placed and the stainless-steel bar were vertically inserted as a shear connector to consolidate between the bottom part and the colonette (Figures 9.2.69-9.2.70). Clamps were also used to fix the tops of the colonettes, pilasters, or door frames. In an irregular case, it was difficult to connect the top of the colonette with the pilaster on the south side of the east entrance because the stone of the pilaster at the same level as the top of the colonette was broken (Figure 9.2.71). Thus, the damaged part of the pilaster was cut out, the colonette was shortened to the same length, and a new stone was installed above the adjacent top surface of the pilaster and colonette (Figures 9.2.72-9.2.73).

3. Lintel

The lintels had collapsed at both entrances before restoration. Fragments of the west lintel were found in the scattered stones around the gate, whereas the east lintel remained missing when the surrounding area was searched. The west lintel was broken and split into three pieces; however, stainless-steel bars were inserted with both cut ends fixed by tightening nuts to connect them as one piece of material, allowing the original west lintel to be reused in its original position (Figures 9.2.75-9.2.77). The east lintel was considered likely to have been transported to a museum or conservation office at some point in the history, as not a single piece of what appeared to be it was found around the gate. As an alternative, it was decided to insert a single new stone as an east lintel and continue the search for museums or archives in the future.

(5) Pediment

Although all pediments had collapsed, except for the eastern pediment before restoration, most of them were scattered stones. In August 2019, immediately after the investigation of the scattered stones, a temporal reassembly of pediments was conducted on the ground. The iconography of each pediment is described in Chapter 10.

1. Structural reinforcement of pediments

Stainless-steel clamps were inserted at the top surface members of the pediment and adjacent roof sandstone to prevent external collapse. Shear connectors were also inserted into the pediments.

2. Missing parts of the pediment

New sandstones were supplemented only in the missing parts of the pediments that supported the original members in accordance with the policy of inserting new stones. The missing flamed ornamental members at the top of the pediment were excluded following the same policy because they were structurally unnecessary.

(6) Roof

The roof sandstones were temporarily assembled on the ground as of December 2019, when the dismantlement was completed, and the initial location of the components was identified in advance. After the reassembly of the walls and entrances, rebuilding of the roof commenced in situ (Figures 9.2.79 and 9.2.84-9.2.86). During the reassembly of the roof, scaffolding was erected inside the building and wooden horizontal supports were temporarily placed at a level above the cornice to stabilize the wall body.

1. Structural reinforcement of the roof

Structural reinforcement of the roof was carried out based on discussions in online meetings between APSARA and TOBUNKEN and advice from the architectural structure expert, Professor KOSHIHARA.

The stones at the corners of the cruciform plan were prone to horizontal deformation. Therefore, clamps were inserted into the upper surfaces of the adjacent sandstones to prevent them from shifting (Figure 9.2.78). At the level of the top of the corbelled arch, where the roof stones protruding from the wall body meet each other, four stainless-steel bars were inserted through four sandstone shorts in an east-west direction to unite them (Figures 9.2.80-9.2.83). The middle part of the layer directly above it, which received the load of the finial, collapsed and was damaged before restoration. Therefore, the broken member was repaired into a single member by penetrating the stainless-steel bars through it, whereas the relatively sound material was repaired by inserting a stainless-steel bar with the ends processed into a clamp shape into the slit made at the bottom face of the stone (Figures 9.2.87-9.2.89). These are expected to reduce the stresses on the stone material in the centre of the roof from the load of the finial base.

After the roofing materials were constructed between Layers 1 and 2, holes were drilled vertically with an electric drill through the upper and lower materials, and stainless-steel bars were inserted to prevent horizontal displacement of the roof members.

2. Missing roof parts

Before restoration, although the roof had largely collapsed, most of the members were found among the scattered stones and could be restored to their original positions. On the roof, only six stones were replaced with the new material.

(7) Finial

The finial was also temporarily assembled on the ground in advance as of December 2019, when the dismantlement was completed. The finial was built from a collection of relatively small stones and had more missing elements than the other parts of the building. Because it was possible to estimate the original shape of the missing parts from the remaining parts, the absent members were supplemented with new materials (Figures 9.2.90-9.2.91).

1. Finial structural reinforcement

The structural reinforcement of the finial was the same as that of the others. The upper surfaces of the adjacent stones were connected with clamps, and holes were drilled vertically to connect the upper and lower stones to prevent them from shifting. Stainless-steel shear connecters were also inserted vertically between the base of the finial and the top surface of the roof to prevent displacement (Figure 9.2.92).

2. Missing parts of finial

The top surface of the topmost lotus pedestal of the finial was originally flattened, and it is highly likely that an ornamental member was placed on top of it. However, no such material was found during the investigation of the scattered stones, and no other similar examples of finial designs were found on the East Gate of Ta Nei. The shape of the missing part was unknown; therefore, we decided not to restore this component (Figure 9.2.95).

(8) Finishing works

1. Repair of missing stone work after rebuilding

Although each stone material was carefully repaired prior to reassembly, repeated readjustment resulted in many small defects in the stone material. These minor defects could also have a negative impact on the stone material itself if rainwater or soil accumulates in these areas and this could also induce plants to take root and move the stone material (Figure 9.2.96).

Therefore, after the rebuilding was completed, the stone condition of the East Gate was checked and repair methods for such minor defects were discussed. After consultation between APSARA and TOBUNKEN, it was decided that (i) relatively large defects should be repaired by filling them with sandstone material and (ii) relatively small defects should be repaired by filling them with lime mortar (mix ratio was; fine sand: slake lime: sandstone powder: brick powder = 3:2:2:1). In total, repairs were performed on approximately 150 parts for stone filling and 80 parts for mortar filling (Figures 9.2.97-9.2.102, and 9.2.112-9.2.113). Because these small pieces are prone to peeling off over time, regular monitoring and continued maintenance are required in the future.

In addition, the stainless-steel bars of Layer 1, the structural reinforcement inserted during roof rebuilding, were unintentionally exposed at the ceiling of the inside building. These were painted with a coloured paint

(JOTUN GARDEX, Premium enamel, a special mixed colour close to No.1916 on a standard soil colour chart) to make them as inconspicuous as possible.

2. Engraving

The surfaces of the new sandstone without carvings were treated in accordance with other existing finishes in the same area. Where a pattern or symmetrically carved image was assumed, the outline of the image or pattern was engraved while avoiding too much detail in the carving (Figures 9.2.103-9.2.104).

The lintel at the east entrance was made of new sandstone, as no existing material was found. As the iconography of the front face of the lintel was completely unknown, no carving was undertaken, and only the surface was smoothed out. The thickness of the newly carved sandstone was retained to allow for the option of replicating the original lintel material in the event that it was identified in a future search.

The colonettes at the east and west entrances were prepared with new materials. However, as the east lintel was uncarved, it was decided that the colonettes at the east entrance were also not carved in detail; only the square foot and the octagonal column above it were roughly shaped. The lintel of the west entrance, on the other hand, was reassembled using the original member, and the iconography, although damaged, was discernible. Therefore, it was decided to sculpt the colonette at the west entrance as the outline of the decoration. To restore these colonettes, carving was performed by comparing the actual measurements of the colonettes of the West Gate and Central Complex at Tanei as well as by referring to the original colonette fragments of the East Gate found in the scattered stones around the gate (Figure 9.2.105).

The quality of the carving finish of the original members varies markedly from place to place, with some detailed carvings abandoned during the process. The four corners of the finial base were carved with Garuda, but the missing parts were replicated with reference to existing sections of the East Gate and Garuda at the West Gate. Because the degree of carving of the pattern details on the cornice varied from face to face at the finial, the newly supplemented material was finished on the surface by following the finish of the adjacent existing stone.

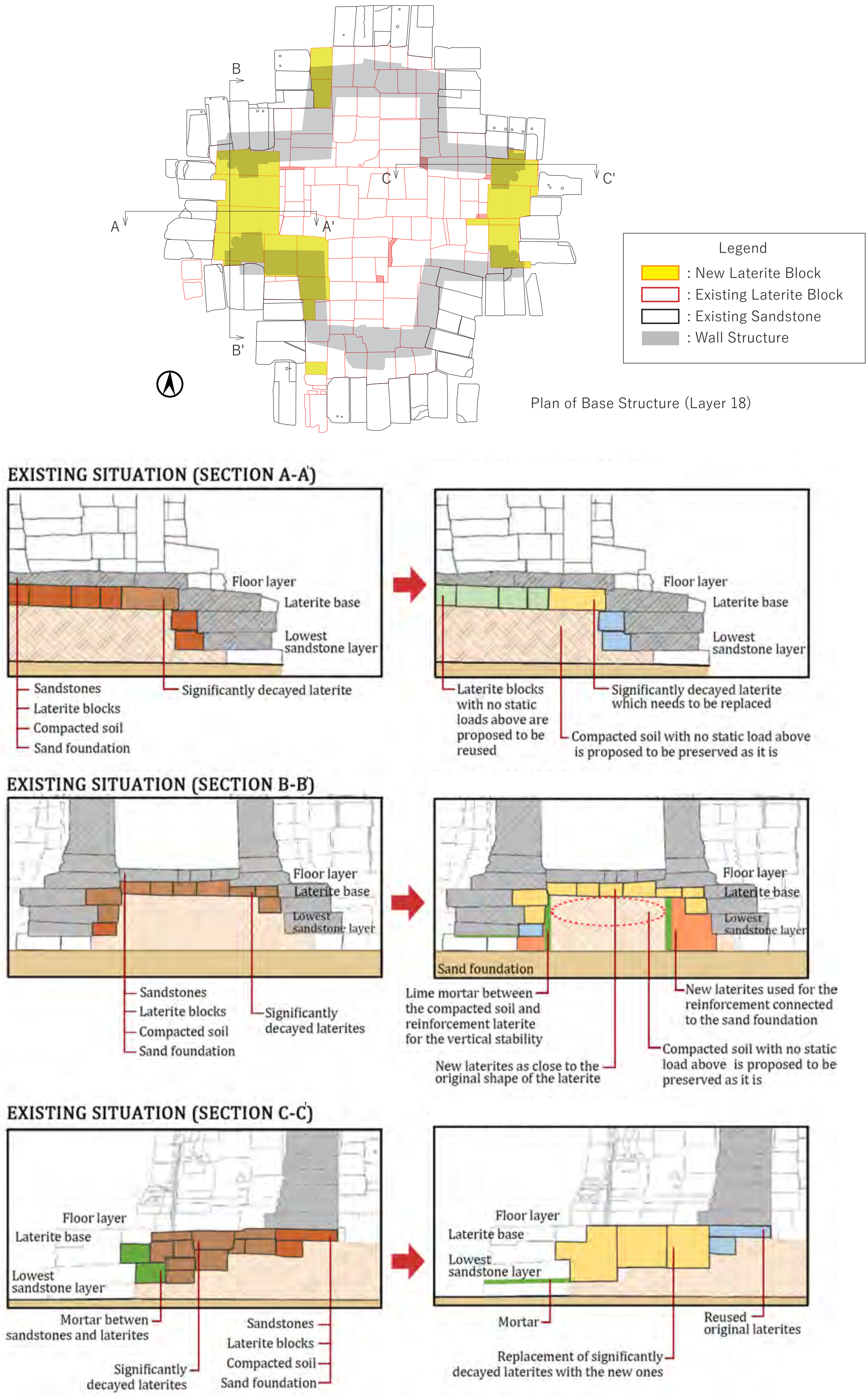


Figure 9.2.25 Diagrams showing the existing situation and the restoration policy for the base

Figure 9.2.26 Outflow of infill soil that caused the brake of exterior sandstone

Figure 9.2.27 Tree root's penetration of the base structure

Figure 9.2.28 Fragile laterite blocks deteriorated by the penetration of tree roots

Figure 9.2.29 Situation of the penetration of tree roots

Figure 9.2.30 Dismantling the exterior sandstone

Figure 9.2.31 Base laterite below Layer 21's the exterior sandstones

Figure 9.2.32 New laterite block inserted in the southeast part of the east wing

Figure 9.2.33 Deteriorated substrate laterite in the east wing

Figure 9.2.34 Deteriorated substrate laterite in the east wing

Figure 9.2.35 Condition of the compacted soil below the deteriorated substrate laterite in the east wing

Figure 9.2.36 New lime mortar compacted on Layer 20's top surface before insertion of new laterite

Figure 9.2.37 New laterite replacing deteriorated substrate laterite in the east wing

Figure 9.2.38 Condition of the substrate laterite in the west wing (Layer 18)

Figure 9.2.39 Condition of the substrate laterite in the west wing (Layer 19)

Figure 9.2.40 Condition of the substrate laterite in the west wing (Layer 20)

Figure 9.2.41 Compaction of Layer 20's top surface in the west wing

Figure 9.2.42 New laterite replacing deteriorated substrate laterite in the west wing

Figure 9.2.43 New laterite replacing deteriorated substrate laterite in the west wing

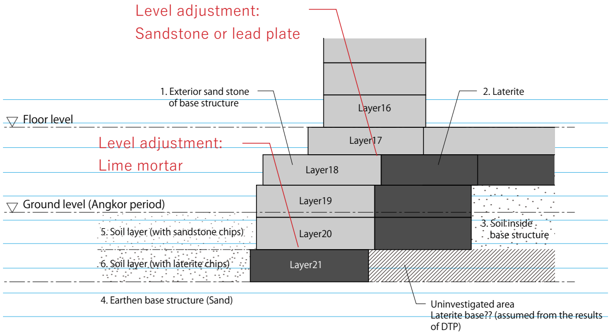


Figure 9.2.44 Use of level adjustment material

Figure 9.2.45 Places lacking exterior sandstones

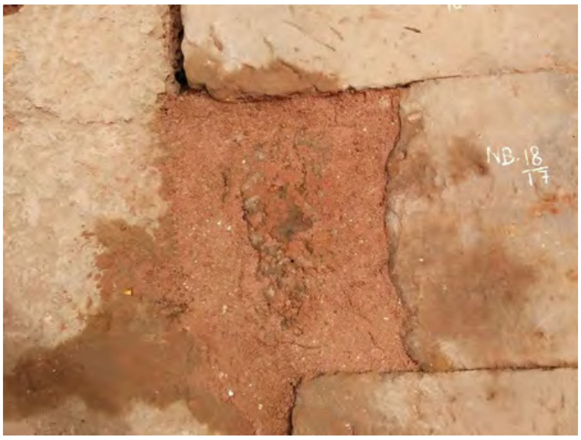


Figure 9.2.46 Use of lime mortar to fill gaps

Figure 9.2.47 Use of sandstone fragments to fill gaps

Figure 9.2.48 Referential sandstones in the south wing

Figure 9.2.49 Compaction of lime mortar in the area surrounding the base structure

Figure 9.2.50 Cutting the displaced laterite to fix the exterior sandstones

Figure 9.2.51 Gap that occurred during trial reassembly in the east wing

Figure 9.2.52 New substrate laterite on the west side of the north wing

Figure 9.2.53 Reassembly of the exterior sandstones in the northwest area

Figure 9.2.54 Gap that occurred between exterior sandstones in the northwest corner of the west wing

Figure 9.2.55 Stainless steel clamps inserted at the northeast corner of the east wing to prevent sandstone displacement

Figure 9.2.56　Trial reassembly of the floor sandstones

Figure 9.2.57　Use of lime mortar to adjust the floor level

Figure 9.2.58　Checking the base structure's level during reassembly

Figure 9.2.59　Wall reassembly

Figure 9.2.60　Reassembly of the wall using two crane tracks

Figure 9.2.61　Scraping new sandstones' surface to place the door frame

Figure 9.2.62 Stainless steel clamps inserted to prevent stone displacement

Figure 9.2.63 Use of stainless steel clamps at the wall corners for consolidation

Figure 9.2.64 Vertical door frame reinforcement

Figure 9.2.65 Horizontal door frame reinforcement

Figure 9.2.66 Trial reassembly of the door frame at the east entrance

Figure 9.2.67 Stainless steel clamps inserted to prevent stone displacement

Figure 9.2.68 Mortise created on the new colonette's bottom surface

Figure 9.2.69 Base of the new colonette, shaped by following the traces on the adjacent stone surface at the northwest corner

Figure 9.2.70 Stainless shear connecter inserted at the bottom of the new colonette at the northwest corner

Figure 9.2.71 Deteriorated top surface of the pillaster at the southwest corner

Figure 9.2.72　Cutting the deteriorated part of the pilaster to consolidate with the new colonette using a clamp

Figure 9.2.73　Use of clamps to consolidate the new colonette, the pilaster and the wall

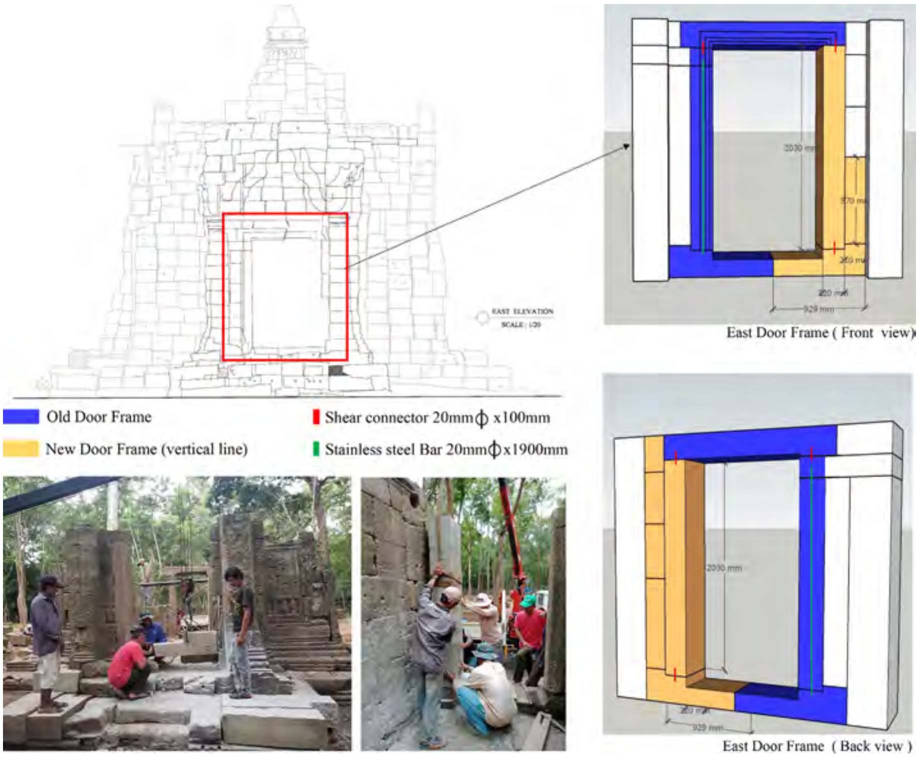


Figure 9.2.74　Original and new members of the door frame at the east entrance

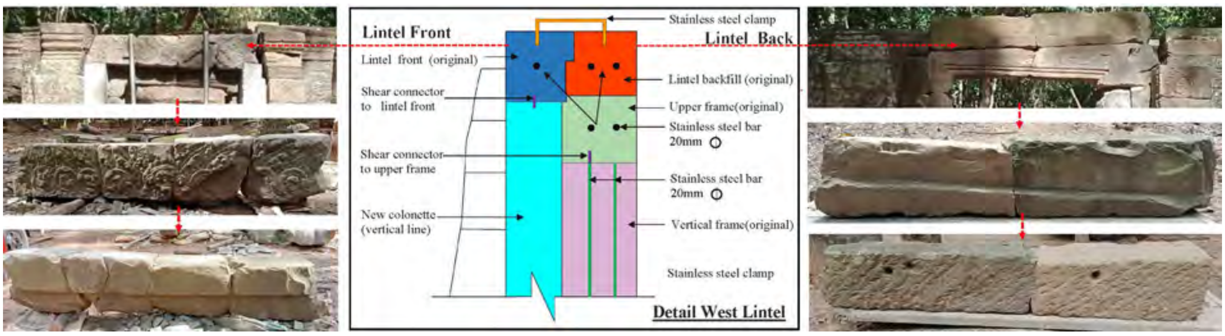


Figure 9.2.75　Reinforcement of the west lintel

Figure 9.2.76　Assembly of the original lintel after repair

Figure 9.2.77　Stainless steel clamps used to connect the lintel and the stone from the rear

Figure 9.2.78　Stainless steel clamps used to consolidate the roof structure's inner corner

Figure 9.2.79　Reassembly of the roof structure

Figure 9.2.80　Consolidation of the cross-vault structure in the east-west direction

Figure 9.2.81　Consolidation of the cross-vault structure in the east-west direction

Figure 9.2.82 Consolidation of the cross-vault structure in the east-west direction

Figure 9.2.83 Layer 01's top surface

Figure 9.2.84 Layer 01's top surface and the use of stainless steel clamps at the pediment

Figure 9.2.85 Curved ditch to place the roof ridge

Figure 9.2.86 Sandstone at the top of the roof structure

Figure 9.2.87 Repairing the topmost layer's roof sandstone

Figure 9.2.88 Consolidation of the central part of the roof using long stainless steel clamps

Figure 9.2.89 Interior view of the cross-vault structure

Figure 9.2.90 Bottom layer of the finial's square base

Figure 9.2.91 East facade of the finial's square base

Figure 9.2.92 Reassembly of the finial

Figure 9.2.93 South wing roof ridge


Figure 9.2.94 Connection between the roof ridge and the finial base


Figure 9.2.95 Flattened upper surface of the top lotus


Figure 9.2.96 Minor defects at the roof's northwest corner


Figure 9.2.97 Retouching work with filling mortar


Figure 9.2.98 Roof at the northwest corner before retouching


Figure 9.2.99 Roof at the northwest corner after retouching

Figure 9.2.100 West lintel and pediment before retouching

Figure 9.2.101 West lintel and pediment after retouching

Figure 9.2.102 Repair with sandstone fragments

Figure 9.2.103 Engraving the finial's new stones

Figure 9.2.104 Engraving the finial's new stones

Figure 9.2.105 Engraving the colonette's new stones, with reference to a fragment of the original colonette

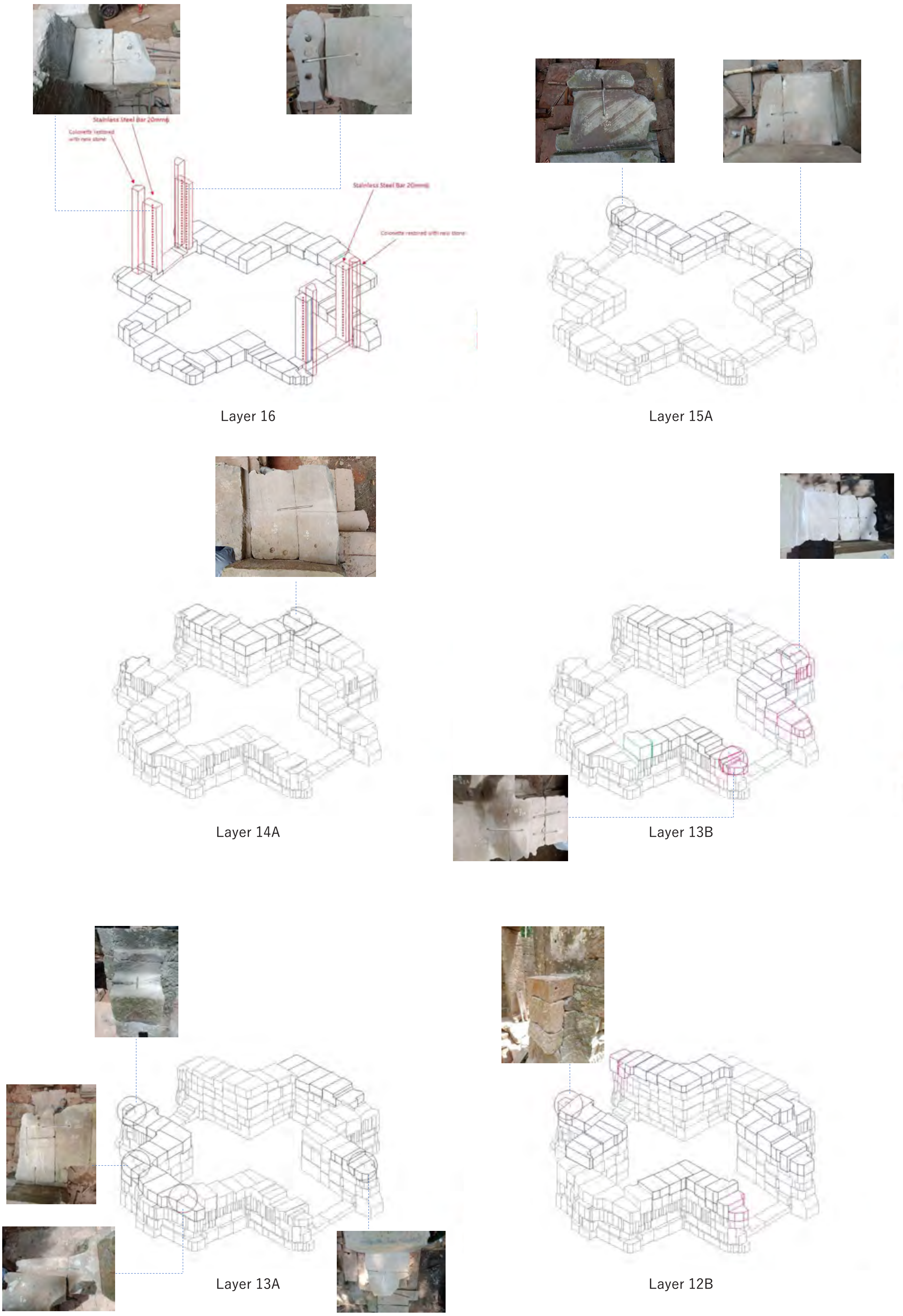


Figure 9.2.106 Structural reignforcement diagram

: Clamp

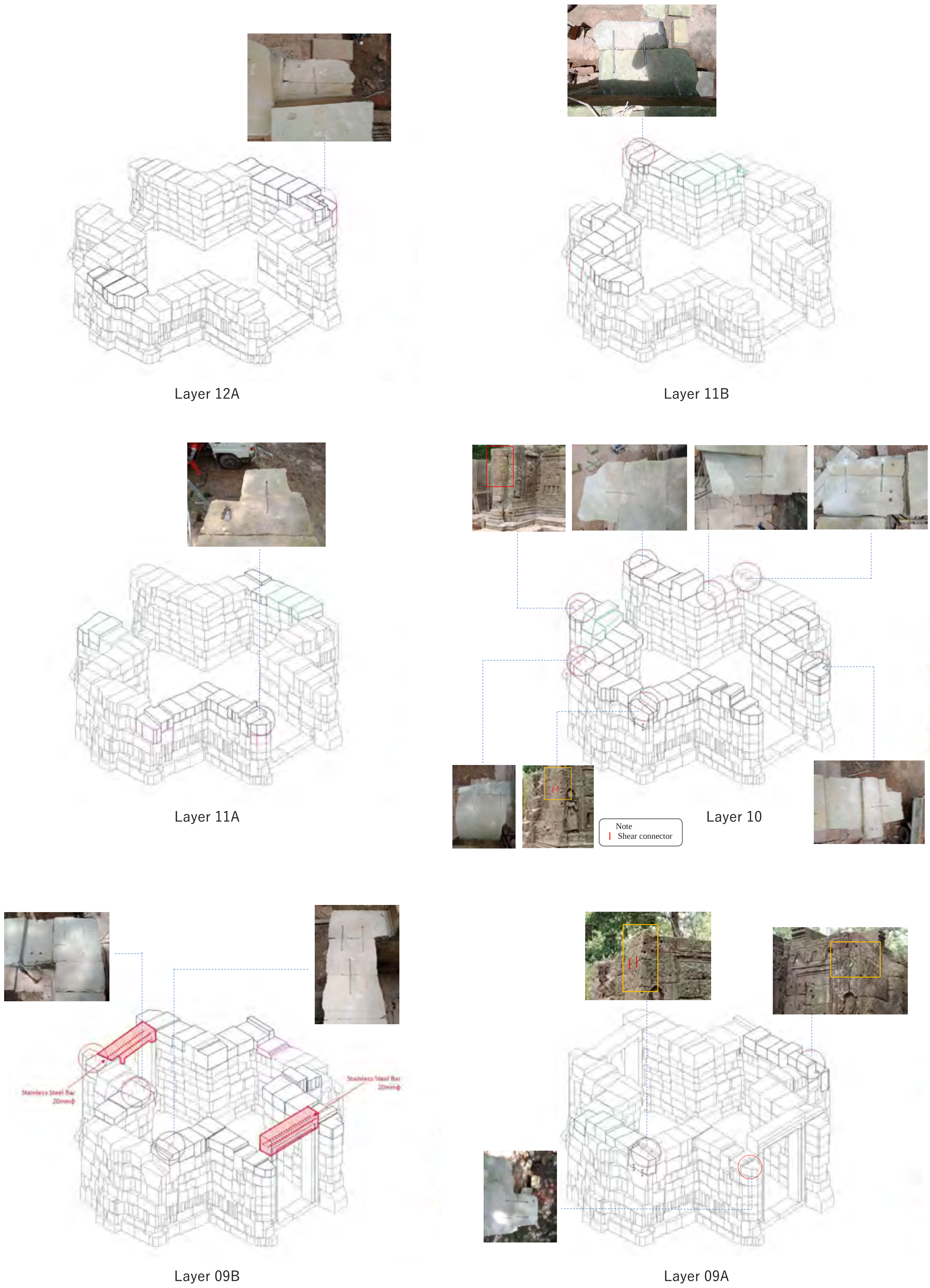


Figure 9.2.107 Structural reignforcement diagram

: Clamp

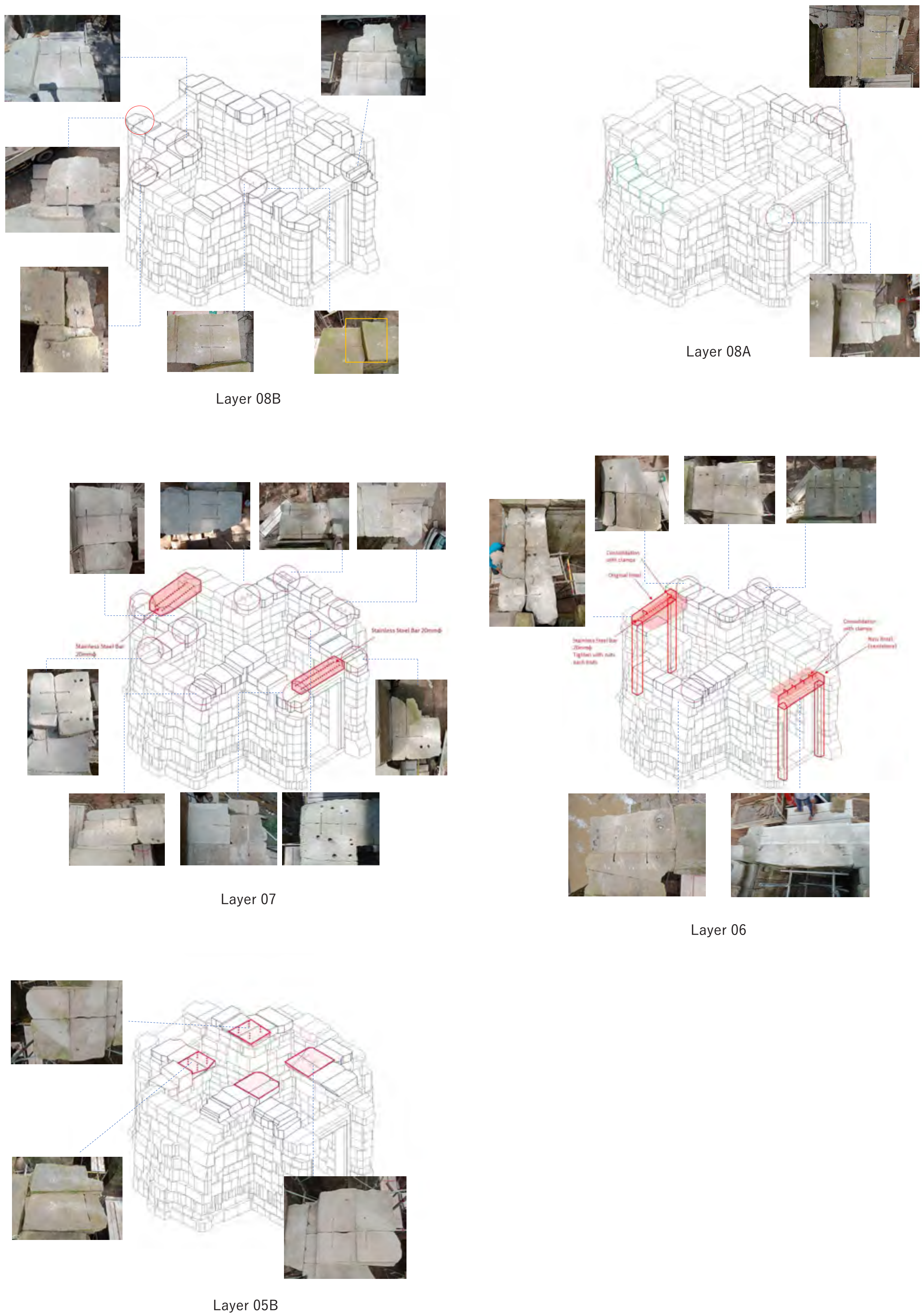
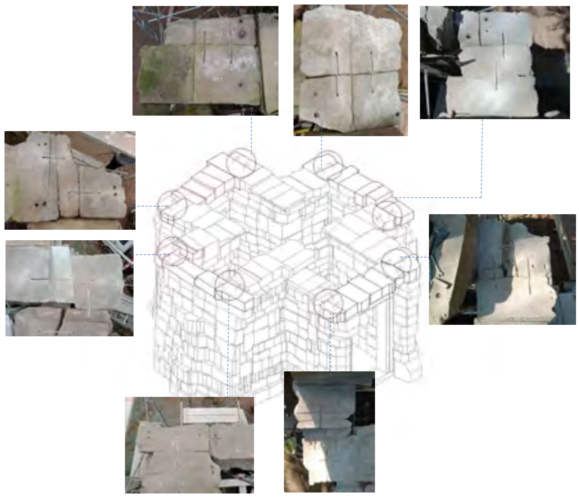
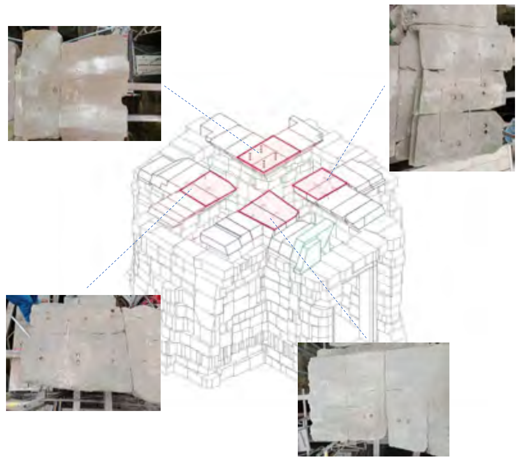


Figure 9.2.108 Structural reignforcement diagram

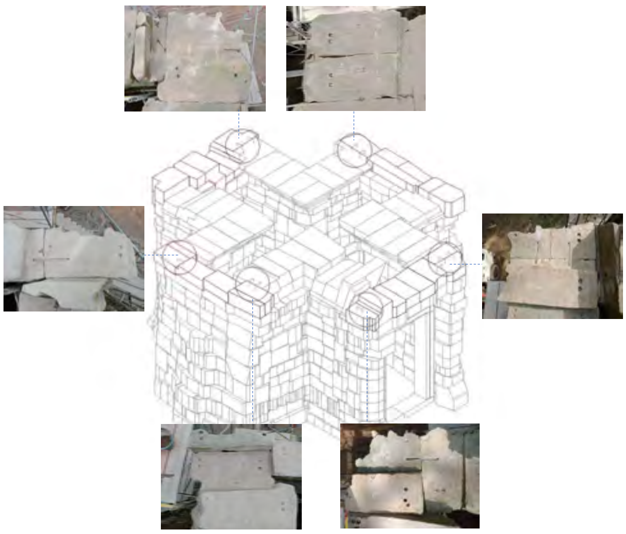
: Clamp



Layer 05A



Layer 04B



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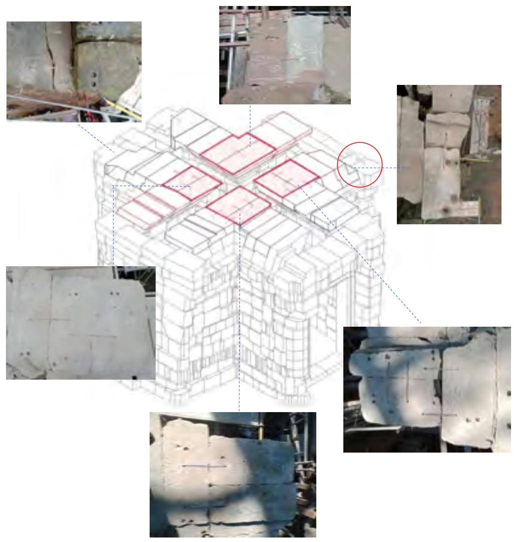
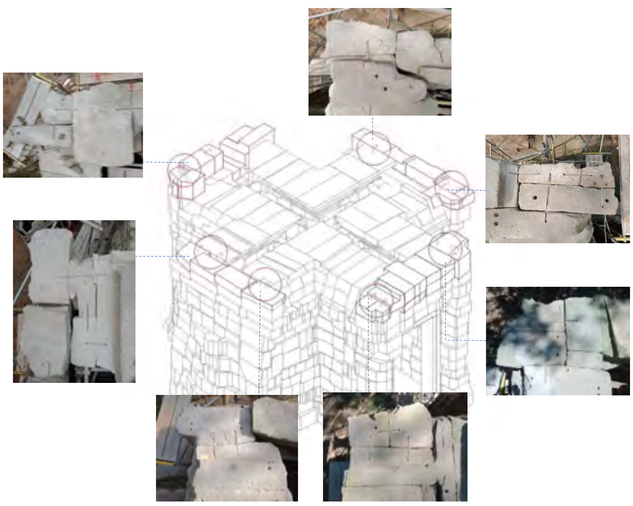


Layer 03B



Layer 03A

Figure 9.2.109　Structural reignforcement diagram

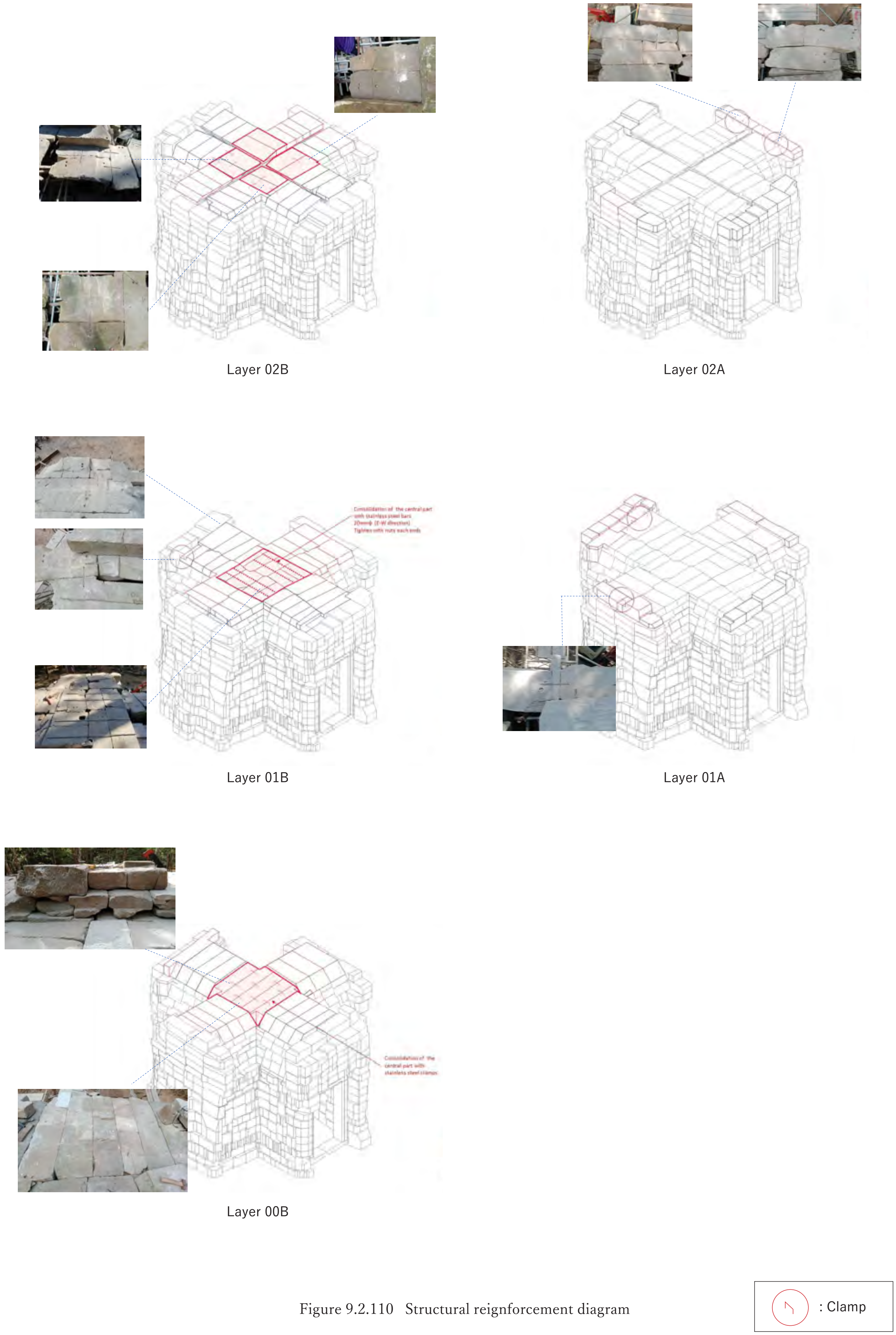
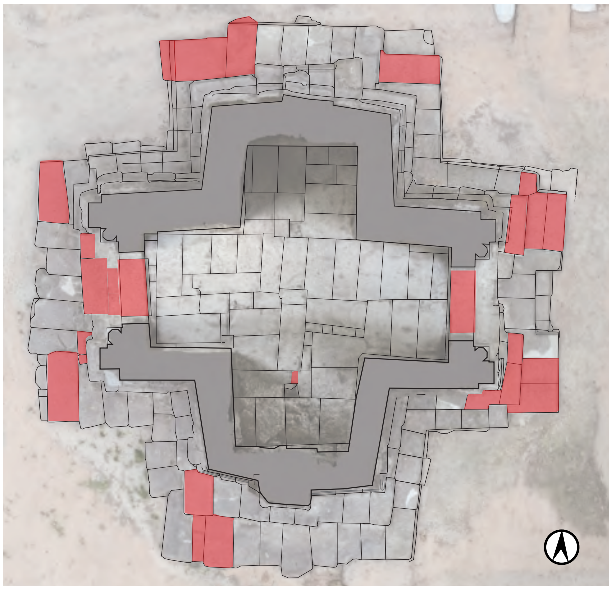


Figure 9.2.110　Structural reignforcement diagram



Plan

: New sandstone (Load bearing material)

Ceiling

East elevation

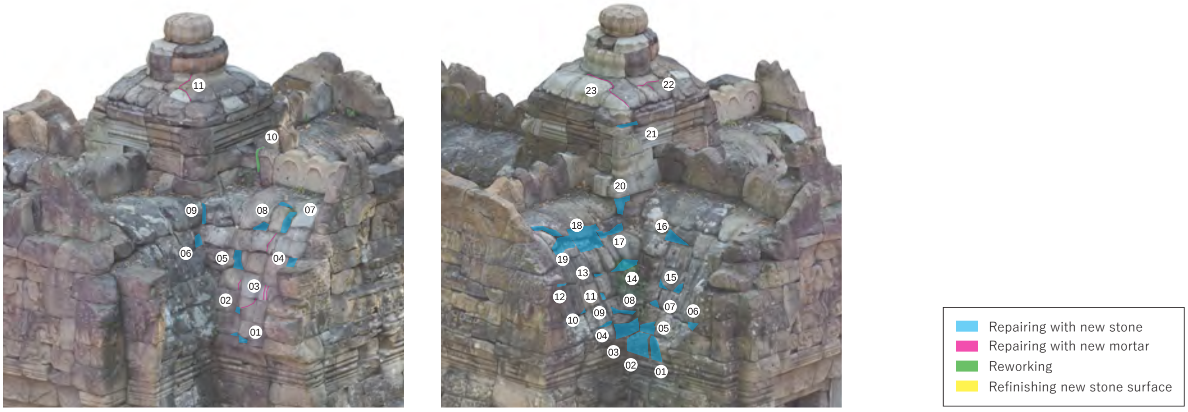
South elevation

West elevation

North elevation

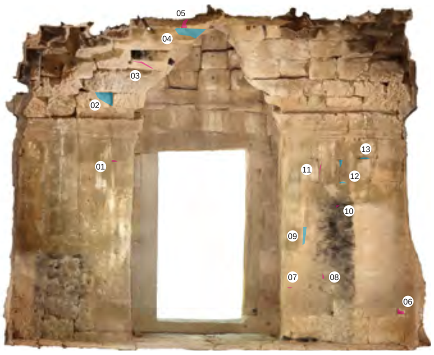
Figure 9.2.111　Newly replaced stones

Figure 9.2.112　Locations of retouching work after reassembly

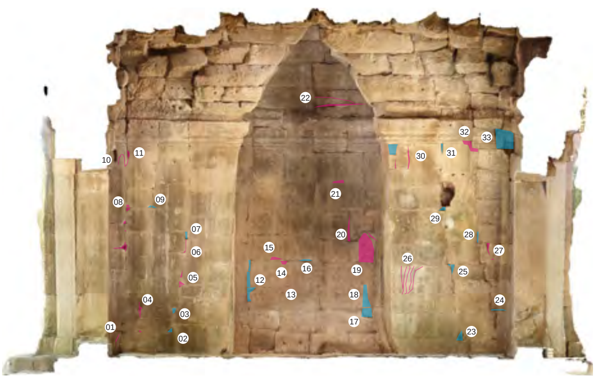


Southwest roof

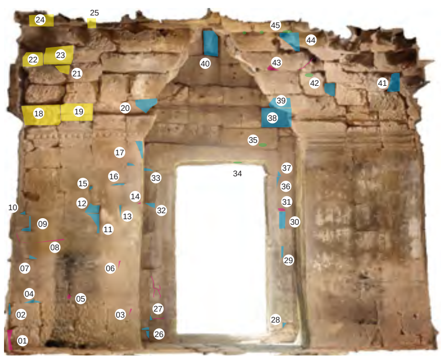
Northwest roof



East interior elevation



South interior elevation



West interior elevation

North interior elevation

Figure 9.2.113 Locations of retouching work after reassembly

9.2.3. List of unreused members of the East Gate

Most sandstones that comprised the East Gate were in good condition and could be reused in restoration work. However, some stones scattered around the East Gate could not be used at their original position in the reassembly work because they were severely damaged or were identified as originating from other structures in the temple.

Unreused stone members were stored as follows:

1. Important archaeological finds stored in museums
2. Original stone members with delicate carvings or fragility—stored at the temple site
3. Original stone members that could not be reused during restoration work: Stored on the south side of the East Gate (Figures 9.2.115, 9.2.117-9.2.118)
4. Leftover materials for restoration work stored on the north side of the East Gate (Figure 9.2.116)

1. Important archaeological findings

The carving of Lokesvara's head was found under the collapsed stones inside the building during the dismantlement of the East Gate, and after the documentation of the discovered status using 3D laser scanning; It was transferred to the Preah Sihanouk Museum and is currently under the custody of the Museum.

2. Original stone members with delicate carvings or fragility

Fragments of colonettes or other stone members with delicate carvings or fragility, which were at risk of breaking or being lost if placed outside, were stored in the storage of the temple.

A portion of the substrate material of the floor stones, a mixture of soil and sandstone chips, was packed in a bag as a sample and stored in a box placed in the temple.

3. Original stone members not reused during the restoration work

Some stone members could not be reused during the restoration work, as some were severely damaged, and others could not be identified in their original position or came from other structures in the temple, not the East Gate.

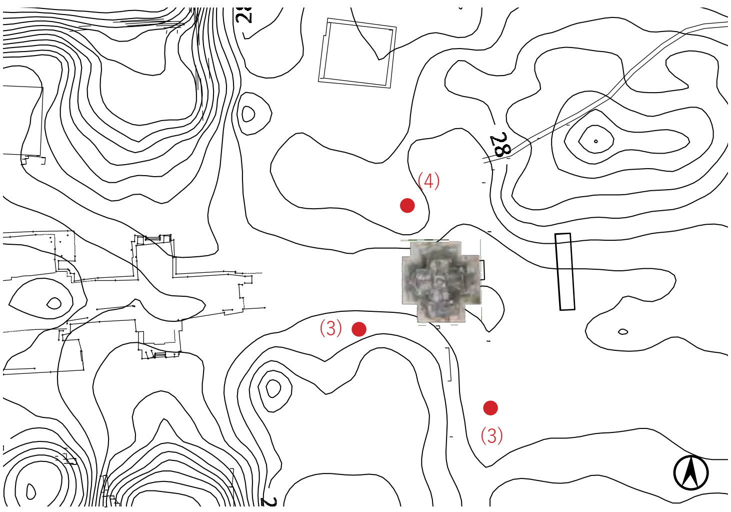


Figure 9.2.114 Locations of stone members that were not reused

For example, two ridge ornamental stones scattered around the East Gate before restoration were found, which were not originally from the East Gate, but presumably from the Outermost Enclosure, which was thought to have been attached to the East Gate. In addition, unidentified sandstones, severely damaged substrate laterite replaced with new laterite during reassembly, and fragments of the original stones were retained tentatively on the south side of the East Gate.

4. Leftover materials for restoration

Leftovers or fragments of the new materials used in the restoration work were kept on the north side of the East Gate.

Figure 9.2.115 Original sandstone members not reused during the restoration

Figure 9.2.116 Leftover restoration materials

Figure 9.2.117 Original substrate laterite blocks below the floor sandstones that could not be reused during restoration

Figure 9.2.118 Original substrate laterite blocks below the floor sandstones that could not be reused during restoration

9.3. Improvement of Water Stagnation Around the East Gate

YAMADA Ayano, KANSHA Hiroo, SEA Sophearun

Water stagnation around the East Gate during the rainy season was one of the issues that should be addressed during the restoration work of the East Gate (Figure 9.3.1). If the ground level had been lowered to the original surface at the time this gate was built to expose the buried base, it was expected that the drainage situation would worsen further. In discussions between APSARA and TOBUNKEN, temporary drainage channels were cut as a solution. After the original terrain status surrounding the East Gate and the presence of drainage equipment were investigated archaeologically, we set up two drainage channels: the western channel reaching from the northwest corner of the East Gate to the northern Moat and the eastern channel reaching from the northeast corner to the pond located northeast of the Ta Nei Temple in June and November 2022, respectively (Figure 9.3.2).

A preliminary archaeological survey was conducted in January 2022 to consider setting up a drainage channel. Three selected areas on the northern half of the east side of the Outermost Enclosure were excavated, and archaeological features and soil layers were confirmed. As the excavation result, it was assumed that natural drainage such as soaking into the ground had functioned at that construction time because the original ground surface keeps almost flat near the East Gate toward the northeast corner of the Outermost Enclosure, and a special drainage channel or equipment was not recognised (Figure 9.3.3). However, natural drainage has not functioned on the current ground surface, and built-up ground on the northern side of the East Gate obstructs drainage and causes problems. As water stagnation may worsen the restored foundation blocks and the surrounding soil of the East Gate, we planned to set up a drainage channel to improve the above issue.

The western drainage channel, which is an open ditch about 35 m long and 1 m wide, was cut from the west side of the East Gate to the northern Moat. Areas were selected so that the channels would not interfere with any archaeological or architectural remains, based on the situation and original surface level around the northeastern corner of the Cruciform Terrace, as revealed by a survey in June 2019 (Ta Nei 2019:35-39). As a result, a 20 m long channel was cut along the main axis of the temple from the northwest corner of the East Gate to the original surface around the northeast corner of the terrace by extending eastward to the north side of the 2019 survey area (Figure 9.3.4). Then, another 15 m long channel was established from the northwest corner of the 2019 survey area to the southeast end of the northern Moat by utilizing the present topography (Figure 9.3.5). During the excavation, roof tile fragments were unearthed in concentration, especially from the bending point toward the end, but their relationship with the temple is unknown (Figures 9.3.5, and 9.3.6).

During the following rainy season, the western drainage channel functioned to release water stagnation only on the west side of the East Gate, but the east side did not improve (Figure 9.3.7). The geographical features of the Ta Nei Temple and its surroundings gradually incline toward the outside of the Outermost Enclosure, and this tendency is obvious in the northeastern area of the site where the Siem Reap River flows. Therefore, another route draining from the northern part of the East Gate to the north outside the site was planned, and an operation to cut the eastern drainage channel was conducted in November 2022.

The eastern channel starts from the northeast corner of the East Gate and progresses 50 m straight toward the north 4m east of the centre of the Outermost Enclosure, parallel to the enclosure (Figure 9.3.8). Because the channel almost reached the centre of the pond in the northeast area of this temple at that point, it was set up such that it turned at right angles to the east and went eastward 10 m more to flow water into the pond (Figure 9.3.9). This 60 m open ditch was made a 1/200 inclination at a minimum against the original ground surface level on the east side of the Outermost Enclosure, which was almost flat. During the excavation of the eastern channel, a part of the colonette made of sandstone, originally installed on the East Gate, was discovered 5.5 m far from the starting point (Figure 9.3.10). And three laterite blocks are observed in front of the pond. These blocks seem to be located in a straight line and surround the pond, but further investigation is necessary to determine the forms of these blocks (Figure 9.3.11).

With the addition of the eastern drainage channel, all water stagnation around the East Gate has now been improved, and the initial problem solved. In addition, after the survey in November 2022, the shoulders of the two drainage channels were cut out in consideration of the collapsing.

Figure 9.3.1 Water stagnation surrouding the East Gate (November 2021)

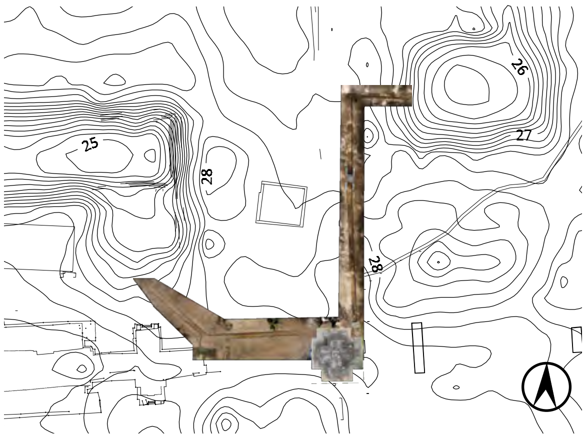


Figure 9.3.2 Location of drainage system

Figure 9.3.3 Digging the western drainage channel

Figure 9.3.4 Eastern drainage channel extending to the northern Moat

Figure 9.3.5 Roof tile fragments concentrated in the western drainage channel

Figure 9.3.6 Roof tile fragments in the section

Figure 9.3.7 Unresolved water stagnation on the eastern side of the East Gate (August 2022)

Figure 9.3.8 Eastern drainage channel from the East Gate to the corner (Left)

Figure 9.3.9 Eastern drinage channel from the corner to the pond (Right)

Figure 9.3.10 Partial colonette found on the East Gate's north side

Figure 9.3.11 Three laterite blocks found beside the pond

Chapter 10

Art Historical Investigation

10.1. Bas-Reliefs on Pediments of the East Gate in Ta Nei:

Some issues concerning the style and source of the iconographic theme

KUBO Makiko

(1) Introduction

In August 2023, the author revisited the Ta Nei Temple for the first time in more than 10 years, having been asked to write this article following the completion of the conservation project, a collaboration between the Authority for the Protection and Management of Angkor and the Region of Siem Reap (APSARA) and the Tokyo National Research Institute for Cultural Properties (TOBUNKEN). During the previous investigation, the East Gate of the Outermost Enclosure[1] of the ruin had fallen stones in many places, and wooden reinforcements had been installed in the remaining parts. Consequently, the author could not confirm the details of the doorway components. During this recent visit, the author had the opportunity to revisit the ruin and investigate the details of the bas-reliefs carved on the pediments of the East Gate at this site.

The purpose of this article is to outline the stylistic features and iconographic representation of the reliefs on the pediments. Additionally, the article aims to summarise the outlines introduced and interpreted in some previous studies, with a focus on the sources for the themes of the reliefs.

(2) Stylistic features of the pediments on the East Gate in Ta Nei

1. Stylistic features of the pediments

Before the restoration project, there were significant amounts of collapsed stones at the East Gate of the Outermost Enclosure in the Ta Nei Temple complex, and most of the pediments on three sides of the East Gate, other than the east side, had collapsed. After the restoration, it became possible to confirm the stylistic features of the details of the pediments. In this section, we will describe the stylistic features of the pediments on the four sides of the East Gate.

The pediment positioned above the east entrance of the East Gate (Figure 10.1.1) features a frame shaped like a combination of five arcs within a wavy band. This frame is adorned with band-like decorations consisting of a continuous pattern (Figure 10.1.2). The band-like decorations are arranged from the outside to the inside of the frame, featuring a pattern of depressed circles, ternate leaves, and flowers. A continuous leaf pattern surrounds the frame. At each end of the frame, a five-headed *nāga* emerges from the wide-open mouth of *makara*. Each *nāga* possesses a long nose that curls upwards.[2] Furthermore, the *nāga* exhibits a complex and decorative facial design, including eyes expressed by layered eyelids and a mouth that curves in several places, resembling the connection of multiple arcs. The frieze at the bottom of the pediment has a shape that tapers off in a straight line at both ends, consisting of rows of a buds-patterned band and beads-patterned band.

A tympanum employs the entire carved surface to represent a single scene. In the centre, a lotus stem

1 The Outermost Enclosure has totally collapsed now.

2 The *nāga* with an elongated nose can also be seen on the pediments of Ta Som, a temple built during the reign of Jayavarman VII (Fig. 10.1.10).

extends, and the *Avalokiteśvara*, with outstretched arms, stands above the lotus flower. The head is missing, as if it were intentionally cut out, but garlands descending from the left and right sides of the head and a bud-shaped hanging decoration on the right ear can be observed. Around its waist, it wears a short *sampot*, along with a wide sash and buckle, but these are worn out. Bangles can be seen on each upper arm, and a wide necklace can be observed on the chest, similarly worn out. Although only two arms can be identified now, observing the traces of chiselling that remains above both arms reveals hints of one bent arm on each side (Figure 10.1.3). These physical features and belongings suggest that this standing figure was originally represented as *Avalokiteśvara* with four arms.

A pair of *apsaras* is flying above the head of the standing figure, while another pair holding garlands is flying on either side of the arms. Moreover, there are two pairs of *apsaras* wearing crowns decorated with feather ornaments, with their palms put together on their chests and one knee down, shown standing upright with one leg stretched out behind them. Four figures with big round bellies sit on each side of the lotus. All the seated figures are dressed in simple robes, with their faces turned upwards as if looking up at the standing figure, and their hands held high. The seated images with round bellies and protruding ribs suggest that they are hungry ghosts holding out their hands to partake in *Avalokiteśvara*'s mercy. The image of the hungry ghosts will be discussed later with references to some previous studies.

Surrounding the Outermost Enclosure extends to the north and south sides of the East Gate of Ta Nei Temple, and a very small portion of the north and south walls of the East Gate where they connect with the Outermost Enclosure remains. On the south side of the gate, only the pediment has reliefs, which is the upper part of the wall (Figure 10.1.4). There are no reliefs on the lower part of the wall. The frame of the pediment is a combination of five arcs in a wavy shape, having similar stylistic features to the pediment on the east side. A boundary line is carved about two-thirds from the top of the tympanum, and in the centre of the boundary line, there are three seated figures with their palms put together on their chests. On the left side, there is another seated figure, which is smaller than the others. Chisel traces on the top of the pedestal behind the central seated figures suggest that the seated figures, which had been carved at the time of production, were chiselled away later. There are four *apsaras* flying above and on both sides of the chiselled sections — the one *apsara* on the lower right has only the back and legs remaining. In the lower one-third of the tympanum, there are five figures with their palms put together, all of them with conical *makuta* on their heads and lotus bud-shaped hanging ornaments on their ears.

The pediment placed above the west entrance of the East Gate has an outer edge frame shaped like a combination of five arcs and consists of similar band-like decorations as the pediment on the east side. The entire surface of the tympanum is carved in relief (Figure 10.1.5). A lotus stem extends from the bottom, and a lotus flower blooms in the centre of the tympanum. A figure stands above the lotus flower. The head of the standing figure has been chiselled away, but from the traces of it, it is inferred that the hair was tied up. In its right hand, something that is probably a flask can be observed, and it appears that it was also holding something in its left hand, but it is difficult to identify because it is worn out. Judging from the chisel traces left on the outside of both arms where the ornaments were displayed, it appears that originally each arm was shown bent at the elbow, and it is thought to have been a standing figure of the four-armed *Avalokiteśvara*. Flower petals are fluttering around the standing figure.[3] There is a pair of devotees on each side of the standing figure's feet, and below that, there are two pairs of devotees on each side. All the devotees put their palms together in front

3 The representation of the fluttering flower petals around *Avalokiteśvara* also can be observed at the pediments of Ta Som Temple (Fig. 10.1.10).

of their chests and raise up one knee. Most of the devotee's heads were damaged, but some remaining parts suggest that they were wearing *makuta* on the tops of their heads. On the right side of the tympanum, there is a small figure sitting with his right hand holding a lotus flower and his left hand on his chest.

The frame of the pediment above the north side of the East Gate is shaped like a combination of five arcs in a wavy pattern and is carved with similar band-like decorations as the pediment on the east side. The surface of the tympanum is divided into two horizontal parts by a boundary line carved with a lotus petal pattern (Figure 10.1.6). In the centre of the upper part of the tympanum, there is a pedestal carved with lotus petals and flowers. On the pedestal and on the left and right sides of the pedestal, only the traces of chisel roughly carved out of the original relief remain. The chiseling traces suggest that a seated figure was depicted on the pedestal, but there are no hints to identify its name or iconographic characteristics. On the upper part of the tympanum, there are four flying *apsaras* wearing crowns, each holding a garland in their hands surrounding the chiseling traces. Additionally, a pair of peacocks is carved on each side of the figure. Five devotee images sitting with their palms put together in front of their chests and one knee up line up on the lower part of the tympanum. They wear ornaments on their chests and upper arms, and *sampot* on their lower bodies. The heads of three out of the five figures have been completely chiselled away or partially destroyed, but the remaining two are closing their eyes, wearing *makuta* on their heads and lotus bud hanging ornaments on their ears.

2. Differences in the decorative band patterns carved on the frames of pediments

As mentioned above, the outer edge frame of the four pediments of the East Gate of Ta Nei is decorated with band-like patterns consisting of depressed circles pattern band, beads pattern band, ternate leaves pattern, and flowers pattern, referred to as Type A. On the other hand, on the frames of pediments of the buildings remaining in the centre of the temple complex, the band-like pattern decorations consist of a different combination. For example, on the pediment on the south side of the northern Entrance Pavilion of the Inner Gallery there are band patterns consisting of two rows of depressed circles pattern, a band pattern with ternate leaves and flowers, referred to as Type B (Figure 10.1.7). Similarly, the pediment on the north side of the southern Entrance Pavilion of the Inner Gallery can be confirmed. What kind of background can be extracted from these stylistic differences in the two types of band patterns?

Maurice Glaize and Philippe Stern pointed out that the construction period of the East and West Gates of the Outermost Enclosure seems to be placed in the late period of the Bayon style, a little later than the construction period of the other buildings in the central part of the temple complex. This conclusion is based on the stylistic features of reliefs on the walls, such as the imitated windows with blinds, the pediments with an image of *Avalokiteśvara* at the centre, and the hairstyle and facial expression of the *devata*.[4] Olivier Cunin, who has studied the construction process of the Ta Nei Temple complex in detail, also highlighted that the Outermost Enclosure with the East and West Gates was constructed later than the other buildings of the temple complex.[5]

Based on these points, to examine whether the difference in the band patterns on pediments could also be a clue to the context of the construction period, we shall compare them with the pediments left in other temple complexes built during the reign of Jayavarman VII. At Ta Prohm, Preah Khan, Ta Som, Krol Ko, Banteay Prei, Banteay Thom, and Banteay Kdei (the buildings in the central part of the complex), the pediments have the same stylistic features as the pediments in the central part of Ta Nei Temple complex, belonging to Type B.

4 Glaize 1944: 179; Stern 1965: 85-86

5 Cunin 2004: 296

On the other hand, most of the pediments of Bayon and Banteay Kdei (Outermost Gate) consist of the same band-like decorations as the pediment of the East Gate of Ta Nei, belonging to Type A. Additionally, these band patterns, such as depressed circles patterned bands and beads patterned bands, are found on the pediments of Angkor Wat, which was built in the first half of the 12th century, earlier than Ta Nei, and on the pediments of Thommanon and Chau Say Tevoda, which were built around the same period as Angkor Wat, belonging to Type A. Moreover, in Preah Palilay and Preah Pithu,[6] which may have been constructed later than Ta Nei, the central band-like decoration consisting of the ternate leaves and flowers pattern has been replaced by a continuous water lilies band pattern, and the depressed circles patterned band and the beads patterned band can be seen on both sides of the central band. Therefore, the band patterns on the pediment of the East Gate of Ta Nei have similarities with the pediments of both styles, such as Angkor Wat style and Bayon style, which are placed before and after the Bayon style period. From this, it is difficult to determine which of the two types of band patterns seen on the Ta Nei pediment is from an earlier period and which is from a later period.

In other words, although it is not possible to confirm the construction period of the central part of the temple complex and the outermost East Gate of Ta Nei Temple only by the stylistic differences in the band patterns on the pediments, at least it is confirmed that the construction dates of the central part of the temple and the East Gate are clearly different. As future work, in addition to comparing the styles of decorative elements other than the pediment, it will be necessary to consider the reasons behind the variations in decorative patterns from various perspectives, such as differences in the period of construction and differences in the sculptor's groups.

3. When were the standing *Avalokiteśvara* figures destroyed and transformed?

As mentioned above, upon observing the pediment on the east side of the East Gate of Ta Nei, the heads of the *Avalokiteśvara* reliefs have been destroyed, as if they had been cut off, and two out of the originally four arms have been chiselled off. Park Hyounggook mentioned that the heads and a pair of missing arms of these standing figures were lost due to the destruction of the Buddhist images.[7]

After the death of Jayavarman VII, many Buddhist temples built during his reign were ordered by Jayavarman VIII (reigned 1243-1295), who believed in the Hindu god *Śiva*, to chisel away the seated Buddha images carved on the walls in the temples (Figure 10.1.8). They transformed the Buddha images into the shape of a Linga, which is a symbol of *Śiva* (Figure 10.1.9), or destroyed the seated Buddha statues enshrined in the temple complexes; this practise is well known.[8] In addition to the destruction of seated Buddha images, there were many cases in which two out of the four arms of *Avalokiteśvara* carved on pediments and lintels were chiselled off during this period.[9] It is interpreted that these acts were done to transform the standing figures into *Śiva*. Although there are some doubts about the interpretation that the figures of *Śiva* were represented by altering the four-armed figures to two, examples of such modifications are found in Preah Khan, Neak Pean, Krol Ko, and Ta Som (Figure 10.1.10), in addition to Ta Nei.

On the other hand, the head of *Avalokiteśvara* is missing in the photo published in Park's 2003 paper, as it is now. However, the head was still present in the photo taken by the École Française d'Extrême-Orient (EFEO)

6 Research to date has not determined the construction dates of Preah Palilay and Preah Pithu. It was initially believed that these were built in the 12th or 13th century, but in recent years there has been an increasing suggestion that these were built in the 13th century or a little later, based on the architectural structure, the themes of the reliefs, and the conditions of preservation (Glaize 1944: 140, 163).

7 Park 2003: 66

8 Cœdès 1968: 212

9 Boisselier 1970: 94

in June 1929 (Figure 10.1.11) and in the plate of the book published by Stern in 1965.[10] From this, it is thought that the head of the *Avalokiteśvara* figure on this pediment was probably cut out for the purpose of grave theft in the late 20th century, during the Cambodian Civil War.

(3) Iconography of the reliefs carved on the pediments of Ta Nei

1. Iconographic interpretations in previous studies

Just before the restoration of the East Gate of the temple complex, only the pediments on the east side remained, but looking at a photo of the EFEO taken in 1929, most of the stones on the east side pediment were still intact, and the reliefs can also be clearly identified. On the other hand, only the lower parts of the pediments on the north and south sides remained, and the west pediment had completely collapsed. In the descriptions of previous studies, most of them focus on the east side pediment.

Etienne Aymonier referred to the reliefs on the pediment of the East Gate, describing the figure in the centre of the tympanum as 'a standing goddess surrounded by monkeys'.[11] Lunet de Lajonquière called his description 'misinterpretation' and mentioned the pediment of the East Gate as follows: 'All the decorations have collapsed at the doorway facing the centre of the temple (the west side), but the pediment of the other doorway (the east side) remains quite intact. The relief is iconographically interesting, and at the centre there is a standing figure of a goddess on a lotus flower. The goddess faces forward, and from her open hands, she shoots out ribbons, and apsaras are holding the ribbons. Pregnant women are sitting on either side of the goddess's feet, offering gifts to the goddess. The sculptors of the time probably carved reliefs from the sides of these women to express the bulges around their waists and sagging breasts.' [12]

It seems that Lajonquière's iconographic interpretation has been used repeatedly for a long time. His interpretation was introduced in a book published by Vittorio Roveda in 2005, stating that 'The Lokeśvara in the centre of the pediment is shown worshiped by a row of fat-bellied figures, with pendulous breasts, possibly mothers asking Lokeśvara's benevolence so they might conceive more children'. [13]

Glaize described the reliefs carved on the pediment of the east side as 'curious' and mentioned that although it was difficult to determine who the seated images around the *Avalokiteśvara*, holding their large bellies and kneeling, were, it showed two possibilities of interpretation.[14] The first possibility is that it represents 'the sickly who seek healing', and the second possibility is that it represents the 'rice thieves' depicted in the hell relief on the gallery of Angkor Wat. The reliefs of 32 hells are carved on the east wall of the southern gallery of Angkor Wat. These reliefs are divided into two tiers, one above the other, and a thin strip separating the two tiers contains the Sanskrit title of each hell and a short inscription about these hells in Old Khmer. The relief of the 15th hell, *Tīkṣṇāyastuṇda*, depicts five very thin men with protruding bellies, beaten with sticks by officials. The inscription reads, '*Tīkṣṇāyastuṇda* hell ... persons who take whatever is not given them by others, who steal

10 Stern 1965. The following photos were taken by the EFEO: EFEO_CAM08913, EFEO_CAM08915, EFEO_CAM08916, EFEO_CAM0891. Furthermore, Hawixbrock's dissertation thesis uses an old photograph taken by the EFEO as a plate of this pediment, so it does not represent the condition of the pediment in the early 1990s, when this thesis was written (Hawixbrock 1994).

11 Aymonier 1904

12 Lajonquière 1911

13 Roveda 2005: 267

14 Glaize 1944: 179

cooked rice ...'[15]

Fifty years later, Christine Hawixbrock submitted her dissertation thesis in 1994, attempting to organise the carvings and inscriptions found in the temples dating from the reign of King Jayavarman VII. She mentioned that the persons with swollen bellies pleading at the feet of *Avalokiteśvara* were hungry ghosts (*preta*[16]), and this relief represents a scene in the *Kāraṇḍavyūha-sūtra*, hereinafter referred to as *KV*,[17] which was compiled in north-western India. We shall return to her points later. Regarding the eastern pediment of the East Gate of Ta Nei, Hawixbrock points out that the *Avalokiteśvara* image standing on the lotus pedestal originally had four arms, but two of those arms were chiselled off. It is also noted that only the lower part of the pediment on the north and south side still has remains of reliefs, with the south side having figures of devotees with their hands put together, and the north side having four figures of devotees.[18]

Park introduced the views that the figures sitting on either side of *Avalokiteśvara* were pregnant women because of their swollen bellies, and that Ta Nei Temple was built to pray for a safe childbirth for the prince, based on the interpretations of these reliefs by Lajonquière and others in previous studies. Park pointed out that these interpretations were a misunderstanding because no similar example of '*Avalokiteśvara Pretasantarpita*' could be found in Cambodia.[19] Based on this, Park concluded that the relief on the east side pediment is '*Avalokiteśvara Pretasantarpita*' based on the text's description and a comparison with similar examples in India and China. He pointed out that the eight seated figures placed to the left and right of the four-armed *Avalokiteśvara* in the centre of the pediment are hungry ghosts, because they are pleading with their hands extended forward, their abdomens are swollen, their cheeks are gaunt, and their ribs and flanks are wrinkled.

2. The issue of the iconography of '*Avalokiteśvara Pretasantarpita*' and its sources

As seen in the previous section, early studies often interpreted the reliefs on the east side pediment as praying for a safe childbirth, but later, they came to be interpreted as hungry ghosts surrounding the *Avalokiteśvara*. As mentioned above, Hawixbrock considered the persons with swollen bellies sitting on either side of *Avalokiteśvara* to be hungry ghosts and suggested that this image may be a representation based on *KV*. The third chapter of the first part of the *KV* describes the salvation of hungry ghosts by *Avalokiteśvara*.[20] When *Avalokiteśvara* visited a town inhabited by hungry ghosts with swollen bellies and small mouths like a needle hall, it let the *Vaitaraṇī* River flow from its 10 fingers and 10 toes, out of compassion. When the hungry ghosts drank the water, they became full-bodied and satisfied, and they gained human hearts and became bodhisattvas, known as 'the one with the desired mouth.' The story states that when a living creature reaches the status of a bodhisattva, the bodhisattva leaves the town.[21]

Focusing on the image of '*Avalokiteśvara Pretasantarpita*' which was actively created in East India, Park examined the relationship between the image and the Tantric Buddhist text *Sadhanamālā*, hereinafter referred to

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15 The inscription is that *Tīkṣṇāyastuṇda* anak ta yok maha ti anak vnaṃ oy lvac pāy, engraved by Old Khmer letter. The word '*tuṇda*' used in the title of the hell, means belly or protruding belly in Sanskrit (Jenner 2009: 433).

16 Hawixbrock refers to hungry ghost as '*preta*' in her paper (Hawixbrock 1994: 82, 86, 89). *Preta* is a Sanskrit word meaning a dead person, a corpse, a ghost before a funeral, and was translated into Chinese and used as the word ' 餓鬼 .'

17 *KV* is the basic text of *Avalokiteśvara*, whose oldest manuscript dates to 6th century (Sakuma 2019: 1-2). Previous research has pointed out that this text is deeply involved in the creation of the *Avalokiteśvara* image in Khmer art (Miyazaki 2010).

18 Hawixbrock 1994: 89

19 Sakuma 2019: 1-2

20 Park 2003: 75

21 Sakuma 2019: 3-5

as *SM*, a valuable and important compilation to Buddhist iconography during the Pala dynasty (mid-8th century to early 13th century) as the image's source.[22] In the *SM*, '*Avalokiteśvara Pretasantarpita*' is called '*Khasarpaṇa Lokeśvara*'[23] and the *SM* describes its characteristics as follows: 'Its body is as white as moonlight, it has a *Jaṭāmukuṭa*, and it is crowned with *Amitābha*, and it sits in a double-lined lotus with a half-lotus position on the moon ring... Its right hand shows the *Varada Mudrā*, and its left hand holds a lotus flower with a stem. It drops the elixir of immortality (nectar) from its hands. It makes a *Sūcīmukha* (hungry ghost) happy. He is pot-bellied, fair-skinned, with his mouth turned up under the drops'.[24]

Park noted that the representations of '*Avalokiteśvara Pretasantarpita*' found in India and Southeast Asia from the 7th century onward do not match the above description in *SM* in many ways. For this reason, it is difficult to regard the representations as a unique iconography or standard of identification for '*Khasarpaṇa Lokeśvara*'. He expressed his opinion that the representation is a variation of the universal expression of the merits of *Avalokiteśvara*, and that this variation was incorporated into the image of '*Khasarpaṇa Lokeśvara*' and written down in *SM* in the 12th century.[25]

As mentioned above, previous studies have shown the possibility of two religious texts that may have served as sources for the relief of '*Avalokiteśvara Pretasantarpita*' in the Ta Nei Temple, such as *KV* and *SM*. Considering that on the pediment of Ta Nei, there are hungry ghosts carved on either side of the central *Avalokiteśvara*, it is more consistent with *KV*'s account of giving nectar from the *Vaitaraṇī* River to a group of hungry ghosts than the *SM* version of giving nectar to one hungry ghost. Since this issue needs to be carefully considered while also taking into account other religious texts, we would like to limit expressing current impressions here.

3. Examples that appear to be '*Avalokiteśvara Pretasantarpita*' in other temples

When investigating the examples of the '*Avalokiteśvara Pretasantarpita*' image and the reliefs left at local ruins in Cambodia, there are related images at other temples besides Ta Nei.[26]

Hawixbrock wrote that reliefs that appear to be '*Avalokiteśvara Pretasantarpita*' were found on three pediments of Ta Nei, including the pediment of the East Gate. In addition to the pediment on the east side of the East Gate, she also mentions the pediment on the south side of the entrance located on the northeast side of the Inner Gallery (Figure 10.1.12). Although the upper part of this pediment has collapsed, the remaining reliefs are in relatively good condition. The tympanum is divided into two horizontal levels, and a standing figure is displayed on the pedestal in the centre of the upper level, with a missing right hand and traces of the left hand. There are chisel traces under both hands, probably some kind of relief cut away later. On each side of the pedestal, there is a pair of seated figures holding a long-handled umbrella, and behind them, there is a pair of figures bowing their heads in worship. In the lower level, there is a person in the centre facing forward, and four persons on each side, with their hair tied at the back of their heads, facing sideways. The four figures sitting on the right side are depicted as pleading with their hands raised high, but their abdomens are swollen, and rib-like lines are carved into their flanks. On the other hand, the four figures sitting on the left are shown

22 Park 2003: 60-61

23 'Kasarpana' means one who glides through the sky and was frequently created in East India during the Pala dynasty (Idemittsu Museum for Arts 1992: 122).

24 Sakuma 2002

25 The description of '*Avalokiteśvara Pretasantarpita*' can also be found in some Chinese-translated texts compiled from the 8th to 11th centuries, earlier than *SM* (Park 2003: 61).

26 Park notes that there are no other examples of this theme reported in Cambodia other than the pediment of the East Gate of Ta Nei (Park 2003: 66).

moving, leaning forward, and looking back, but they do not appear to be pleading with their hands together. She pointed out that the eight figures sitting sideways on the lower level might be hungry ghosts.[27] However, the characteristics of the hungry ghosts are only recognised in the four figures sitting on the right side with their hands raised, so the question is how to interpret the four figures on the left side and the seated figure facing forward in the centre.

In addition, she reported that another relief of '*Avalokiteśvara Pretasantarpita*' was found on the south pediment of the cruciform-planned East Tower Shrine at the east side of the Central Tower Shrine in the Inner Gallery of Ta Nei. The legs of a male standing figure remain on the pedestal in the centre of the upper tympanum of this pediment (the upper part is missing), and on each side of the pedestal, there are two pairs of sitting acolytes holding umbrellas with long handles. The lower tympanum carves a row of large-bellied women, or hungry ghosts, all kneeling down and praying upward. She pointed out this relief seems to depict the scene represented in the *KV*, like the relief on the East Gate pediment.[28] Unfortunately, this pediment has now collapsed, and we have not been able to confirm it; therefore, this article would like to introduce it here based on the report from Hawixbrock.[29]

Moreover, the author's field survey this time confirmed a relief representing hungry ghosts in Neak Pean, which was built in *Jayatatāka*, an artificial reservoir during the reign of King Jayavarman VII (Figures 10.1.13 and 10.1.14). At Neak Pean, a circular island platform is built in the centre of an artificial square pool measuring 70m on each side, and a central sanctuary stands on top of the platform. Secondary pools measuring 25m on each side are installed on four sides of the central pool, and the central pool serves as the main tank, draining water to the surrounding secondary pools connected by waterways.[30] Four chapels decorated with many representations of *Avalokiteśvara* images connect the central pool to each of the secondary pools on the waterways. Each chapel is open to the secondary pool, with the line of the opening arch following the vaulted roof over the water channel connecting the central pool and the four secondary pools, and three large and small pediments were placed on each of the three sides of the roof, that is the remaining three sides except the one with the opening.

On the tympanum of the pediments, there are reliefs of the four-armed *Avalokiteśvara* and devotees, and there are also small reliefs on the sides of the frame of the pediments. On the north side of the frame of the east pediment on the east secondary pool, two hungry ghosts were also seen, among a series of leaf-shaped niches representing ascetics with their hands put together. Both hungry ghosts had swollen bellies, representing ribs on their flanks, and their joined hands were raised high, which were common features with the hungry ghost seen on the pediment of Ta Nei. However, there are differences in the depiction of the scene. This is because in Ta Nei, the scene of *Avalokiteśvara* pouring water on hungry ghosts is depicted on one pediment, while in Neak Pean, two small images of hungry ghosts are depicted in separate places from the pediment representing *Avalokiteśvara* (Figure 10.1.15). This is probably because the merits of *Avalokiteśvara* in saving even the hungry ghosts are expressed by combining the pediment representing *Avalokiteśvara* with the devotees bowing at its feet and the image of hungry ghosts carved around its periphery.

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27 Hawixbrock 1994: 85-86

28 Hawixbrock 1994: 82

29 Hawixbrock points out that hungry ghosts are also depicted on two pediments at Preah Khan in Kampong Svay, the present-day Preah Vihear province (Hawixbrock 1994: 213).

30 Glaize 1944: 214

(4) Concluding remarks and future perspectives

Up to this point, we have provided an overview of the stylistic features and iconographic representations of the pediment of the East Gate in Ta Nei, confirming the interpretations of previous studies. First, by pointing out the differences in the band pattern on the frame of the pediments between the East Gate of the Outermost Enclosure and the buildings in the central part of the temple complex in Ta Nei, and by comparing them with other temples constructed in the same period, we found some clues to consider the style of the pediment of the East Gate in Ta Nei.

Second, based on the results considering the source of the '*Avalokiteśvara Pretasantarpita*' image represented on the pediments of the East Gate in Ta Nei, we could confirm a certain consistency between the images on the relief and the descriptions in *KV*. This is an issue that should be further studied in the future, along with the relationship between *KV* and other relief images from the Angkor period. Many aspects pertaining to the religion underlying the art and architecture in the Angkor period are yet to be elucidated, including what kind of religious texts were prevalent at the time. This article could provide a starting point that will lead to future research.

Finally, on some pediments and lintels in the central part of Ta Nei, there are many reliefs of Buddhist stories, including images of the legends of Buddha and *Jātakas*. By comparing the images in the central part of Ta Nei with the outermost section, which we examined in this article, it will be possible to show the layout of the images over the entire temple complex, as well as the changes in layout trends along the construction process of this temple complex. We realized that the style and iconography of the reliefs were revealed through the restoration work for the East Gate, and obtaining new perspectives is a great achievement of the collaborative work between APSARA and TOBUNKEN.

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Figure 10.1.1　East pediment of the East Gate, the Outermost Enclosure, Ta Nei

Figure 10.1.2
Outer frame of the east pediment of the East Gate, the Outermost Enclosure, Ta Nei

Figure 10.1.3
Bas-relief on the upper layer of the east pediment of the East Gate, the Outermost Enclosure, Ta Nei

Figure 10.1.4
South pediment of the East Gate, the Outermost Enclosure, Ta Nei

Figure 10.1.5
West pediment of the East Gate, the Outermost Enclosure, Ta Nei

Figure 10.1.6
North pediment of the East Gate, the Outermost Enclosure, Ta Nei

Figure 10.1.7
Detail of the south pediment of the north gate, the Inner Gallery, Ta Nei

Figure 10.1.8
Lintel on the west doorway of the central shrine in the southern subsidiary complex inside of the 3rd enclosure, Ta Prohm

Figure 10.1.9
East pediment on the north pool, Neak Pean

Figure 10.1.10
Bas-relief on the west reconstructed pediment of the north library in the 1st enclosure, Ta Som

Figure 10.1.11
East pediment of the East Gate, the Outermost Enclosure, Ta Nei, in 1929 (EFEO_CAM08916)

Figure 10.1.12
South pediment of the northeast Gate, the Inner Gallery, Ta Nei

Figure 10.1.13
North side of the frame of the east pediment on the east secondary pool, Neak Pean

Figure 10.1.14 Detail of the Figure 10.1.13

Figure 10.1.15 North pediment on the east secondary pool, Neak Pean

Chapter 11

Relevant Works

11.1. Conservation of the Surrounding Area of the East Gate

TOMODA Masahiko

The completion of the East Gate restoration paved the way to the recovery of the main entrance approach area, one of the main goals of the Conservation and Sustainable Development Plan for Ta Nei Temple. Related to this, a summary of the following conservation plan for the surrounding area of the East Gate is presented here. Please refer to already published or to-be-published annual project reports for the details of archaeological excavations mentioned in this section.

(1) Investigation and conservation for the west area of the East Gate

Excavations were conducted in a 10 m by 10 m area around the East Gate to detect scattered stone materials in 2018, in which no structural remains were newly detected except for the basement of the Outermost Enclosure connecting to both the north and south sides of the East Gate. However, a few heavily deteriorated laterite materials were found at the west side of the pre-restored East Gate base structure (Figure 11.1.1). They were not considered as materials from its original construction, but suggested that some remodelling could have been conducted using these materials afterwards. In the following year, 2019, a small excavation was conducted around the north-eastern external corner of the Eastern Cruciform Terrace, the entrance of the Central Building complex, located at the west side of the East Gate. This excavation confirmed that some extensions had been made at the front edge of the Terrace. The appearance of detected laterite ruins suggested a possibility of the existence of a causeway connecting between the East Gate and the Eastern Cruciform Terrace. As a causeway-like pavement made of laterite blocks can be recognised between the West Gate and the Western Cruciform Terrace at the east of the West Gate even now, it is also highly possible that a similar causeway existed at the west side of the East Gate (Figure 11.1.2).

Figure11.1.1 Laterite members of the East Gate base structure at the southwest corner

Figure11.1.2 Laterite pavement to the east of the West Gate

Therefore, in 2022, when most of the East Gate restoration was completed, excavation was conducted at the east side of the Eastern Cruciform Terrace, 8 m from north to south by 9 m from east to west, down to the original ground surface. However, no remains were newly found except for some parts connected to the remains detected in the excavation area of 2019, and no clues were found to clearly suggest the existence of the pavement causeway (Figure 11.1.3). As there are still some areas where no excavation has been conducted between the excavation area in 2022 and that in 2018, we expect to have some conclusion for the question as to whether the causeway at the west side of the East Gate existed or not.

The ground around the East Gate was dug to the original ground surface level after setting up tentative drainage ditches soon after the Gate restoration was completed as described in Section 9.3 (Figure 11.1.4). The situation is the same as for the excavation area at the east side of the Eastern Cruciform Terrace. Once the excavation between the Eastern Cruciform Terrace and the East Gate is completed, the whole area from the East Gate to the Cruciform Terrace is planned to be conserved at a level closer to the original ground surface.

(2) Conservation of the original approach way from the Terrace on the West Embankment of the East Baray to the East Gate

Regarding this approach way, based on three excavations held from 2017 to 2018, the existence of a compacted surface with sandstone gravels was confirmed under approximately 50 cm to 70 cm below the current ground surface, which is considered to have been the main approach way to the Temple at that time. The approach way has a width of approximately 11 m and slopes gradually downward to the East Gate. Both the north and south sides of the approach way are about 50 cm higher than the approach itself (Figure 11.1.5). We were concerned that if the original ground form of the approach way were to be restored, the rainwater could collect and flow into and around the East Gate, especially during the rainy season. In addition, the landscape of the approach way from the embankment to the East Gate can be visually recognised as it is (Figure 11.1.6). Therefore, only weeding at the current ground surface will be conducted in the area of the approach way. For now, consideration is needed as to whether further tree cutting should be conducted.

Figure11.1.3 Excavation between the East Gate and Cruciform Terrace

Figure11.1.4 Water drainage during the rainy season

(3) Conservation of the Terrace on the West Embankment of the East Baray

From the time of the discovery in 2017 until 2023, we have conducted several excavations on the laterite Terrace on the West Embankment of the East Baray, which is the starting point of the main approach way to Ta Nei Temple (Figure 11.1.7). The excavations revealed the following: this Terrace is located slightly east of the centre of the West Embankment; it forms an asymmetric cross shape with the shorter east wing; it used to have a tile-roofed wooden structure on it; the Terrace was artificially destroyed and its laterite blocks were extensively taken away. The remaining condition was devastated except for the relatively intact central parts and the west wing where the outer peripheral stone blocks remain. Therefore, the overall form and size of the Terrace, especially those of its north and south wings, could not be identified. As a result, the restorative conservation of the Terrace was abandoned, and it was decided just to protect and care for the current remains with mounds. Associated with the clearance of the trees and earth removed by the excavation, some work for improvement of the landscape is planned.

On the other hand, on the West Embankment of the East Baray, where the Terrace is located, a laterite structure remains on the east extension of the central axis of Ta Keo Temple, and a large-scale sandstone cruciform terrace along the east extension of the main axis from the Angkor Thom Royal Palace main gate through its Victory Gate exists (Figure 11.1.8). Recent maintenance has enabled tourists to walk between these two structures. The Conservation and Sustainable Development Plan for Ta Nei is targeting to extend this pathway north to the Terrace of Ta Nei on the West Embankment. Currently, at APSARA, implementation planning is under discussion, including pre-implementation archaeological investigation. Once this is realised, the original approach way to Ta Nei Temple will be revived, and will place the Ta Nei Temple remains in a new role as a core site for eco-tourism from Ta Prohm to Preah Khan.

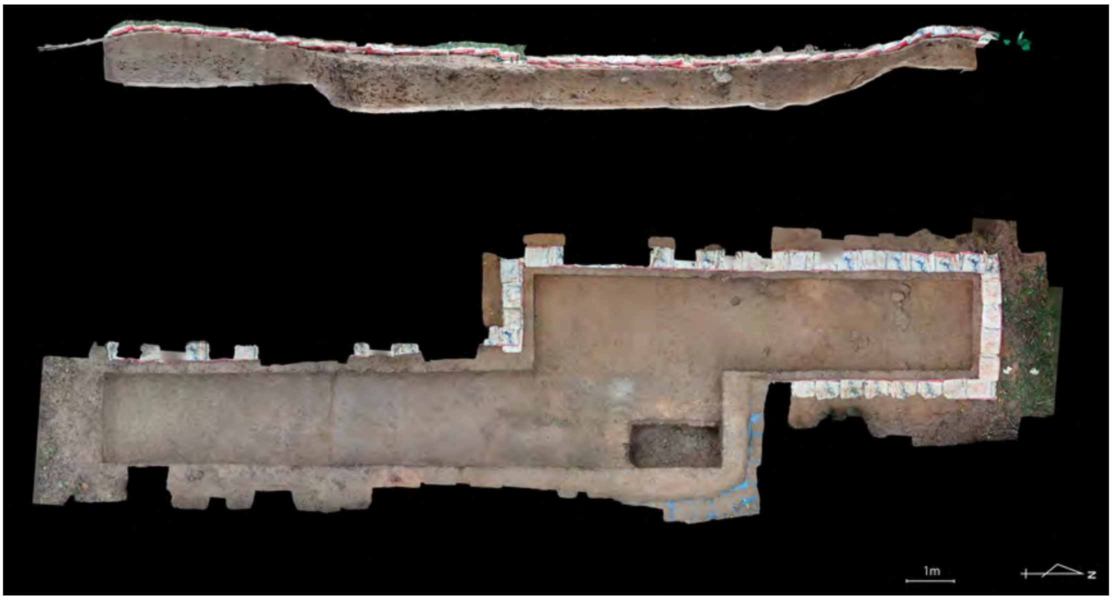


Figure11.1.5 Remains of the original approach way

Figure11.1.6 Distance view of the East Gate from the Terrace on the Embankment

Figure11.1.7 Overall view of the Terrace on the Embankment

Figure11.1.8 Cruciform Terrace on the Victory Gate's main axis

Photos

East elevation after restoration

Southeast elevation after restoration

South elevation after restoration

Southwest elevation after restoration

West elevation after restoration

Southwest elevation after restoration

North elevation after restoration

Northeast elevation after restoration


East inner elevation after restoration


South inner elevation after restoration


West inner elevation after restoration


North inner elevation after restoration

Northeast inner elevation after restoration

South inner elevation after restoration

Southeast side of the ceiling after restoration

Northwest side of the ceiling after restoration


West side of the ceiling after restoration


Ceiling after restoration

East elevation before restoration in July, 2017

Southeast elevation before restoration in July, 2017

South elevation before restoration in July, 2017

Southwest elevation before restoration in July, 2017

West elevation before restoration in July, 2017

Northwest elevation before restoration in July, 2017

North elevation before restoration in July, 2017

Northeast elevation before restoration in July, 2017

East elevation before dismantlement (after removal of the scattered stones) in September, 2019

Southeast elevation before dismantlement (after removal of the scattered stones) in September, 2019

South elevation before dismantlement (after removal of the scattered stones) in September, 2019

Southwest elevation before dismantlement (after removal of the scattered stones) in September, 2019

West elevation before dismantlement (after removal of the scattered stones) in September, 2019

Northwest elevation before dismantlement (after the removal of the scattered stones) in September, 2019

North elevation before dismantlement (after the removal of the scattered stones) in September, 2019

Northeast elevation before dismantlement (after the removal of the scattered stones) in September, 2019

East inner elevation before dismantlement

South inner elevation before dismantlement

West inner elevation before dismantlement

North inner elevation before dismantlement

Southeast inner wall before dismantlement in March, 2019

Northeast inner wall before dismantlement in March, 2019

East ceiling before dismantlement in March, 2019

South ceiling before dismantlement in March, 2019

South ceiling before dismantlement in March, 2019

Northeast ceiling before dismantlement in January, 2019

Cross Vault before dismantlement in March, 2019

South side of the west wing's roof before dismantlement in March, 2019

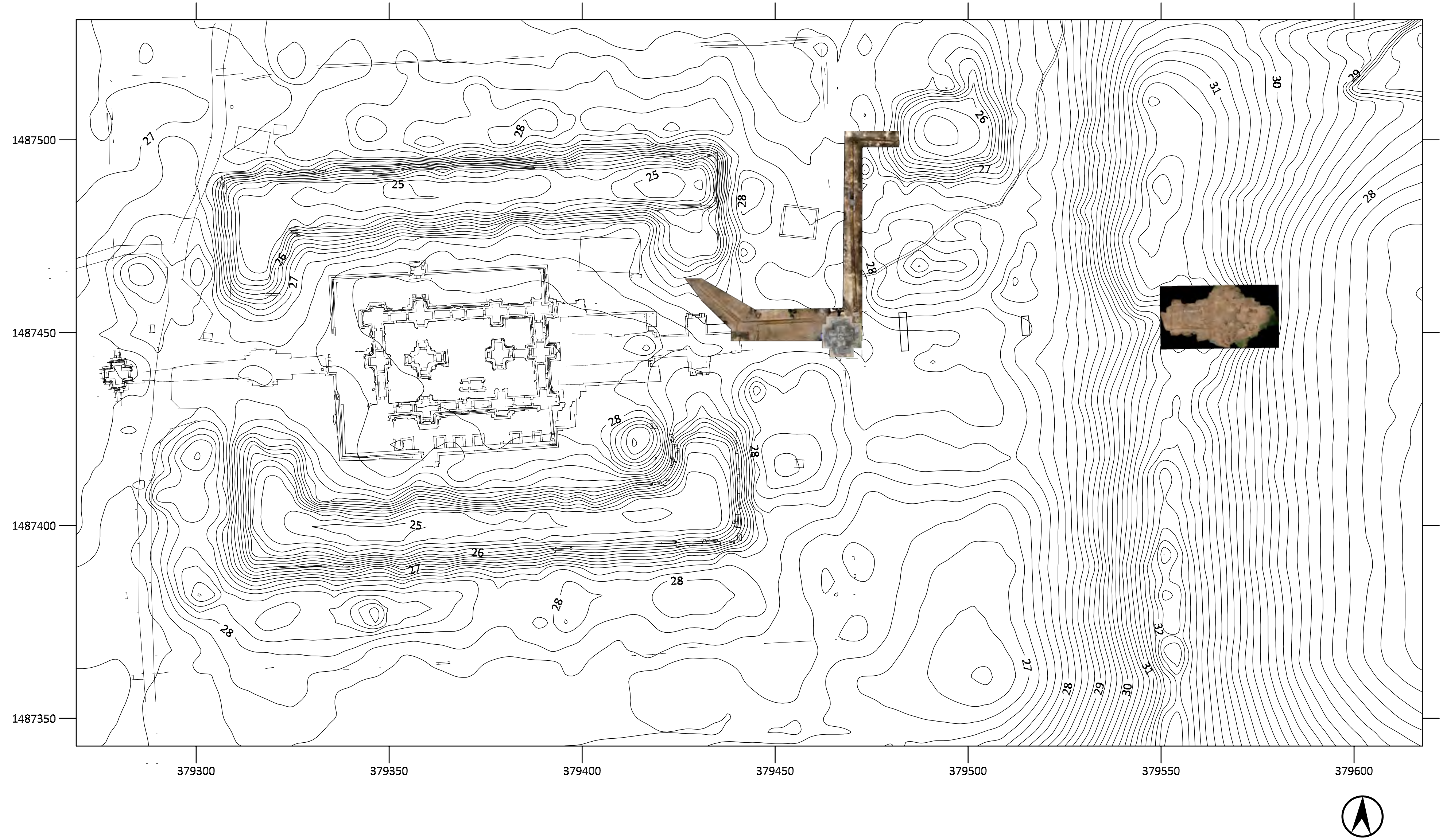
Collapsed stones inside the East Gate in March, 2019

Drawings

Drawings

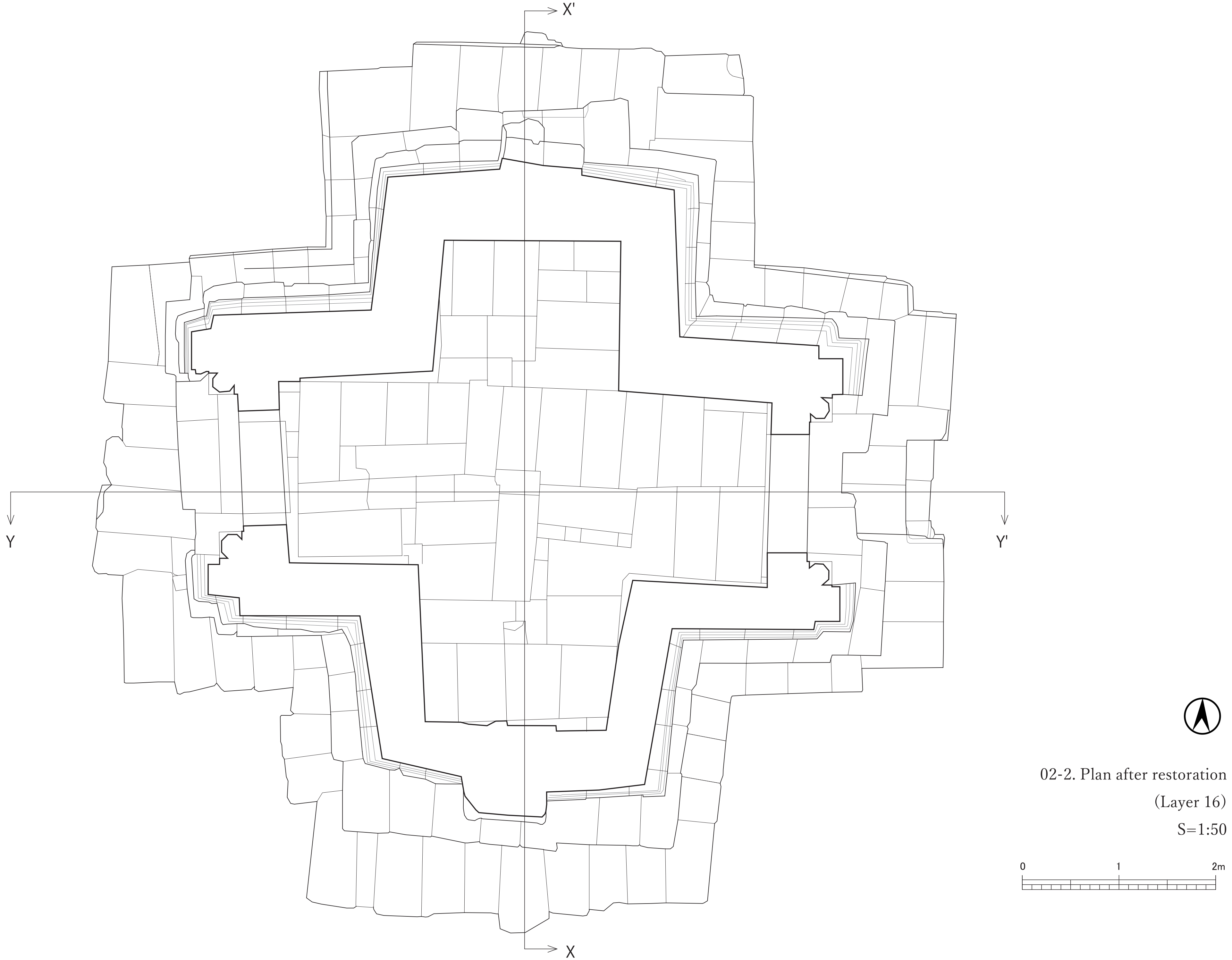
Note

- Site plan (No.01) was created as an outcome of the field training programme on the architectural measurement techniques in 2012-2013, and added the photogrammetric plan to depict the survey area conducted in the period from 2017 to 2022.
- Drawings after restoration (No.02-09) were prepared by tracing the lines of stone joints and curvings on the 2D images of the 3D model, which was created from drone photogrammetry.
- Drawings before restoration (No.10-17) were prepared by tracing the lines of stone joints and curvings on the combined 2D images of the 3D models, which were created from 3D laser scanning survey conducted in March, October 2019, and February 2020 in collaboration with Dr. OISHI Takeshi's Laboratory in the University of Tokyo .
- Plan of each layer during dismantlement (No.18-36) were created from 3D photogrammetry. *non-scale
- Plan of each layer during dimantlement (No.37-39) were created from hand measuring and CAD drawings.



01. Site plan S=1:700

02-1. Plan after restoration
(Layer 16)
S=1:50

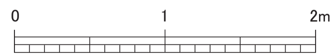


02-2. Plan after restoration

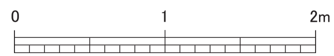
(Layer 16)

S=1:50

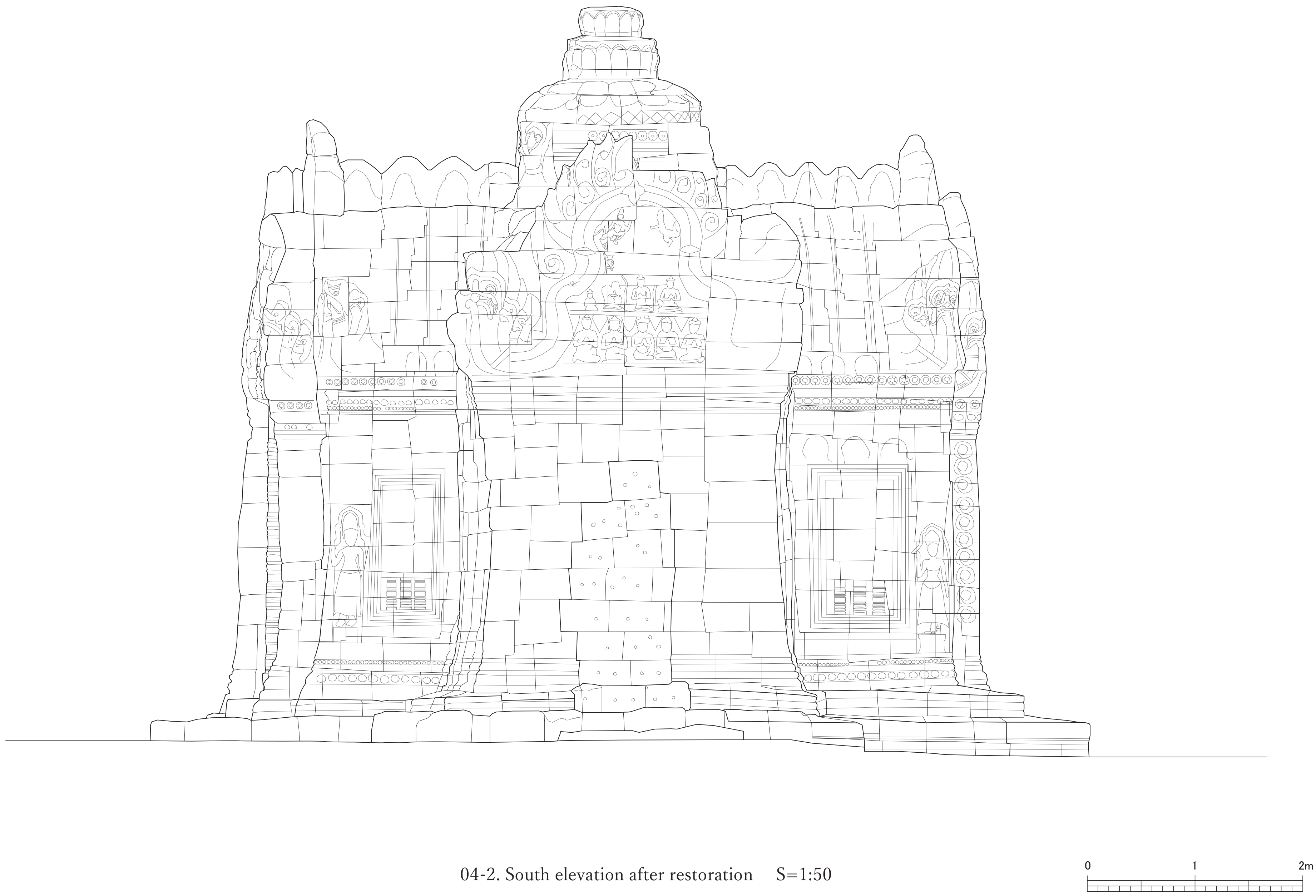
03-1. East elevation after restoration　S=1:50



03-2. East elevation after restoration S=1:50



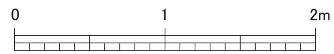
04-1. South elevation after restoration S=1:50



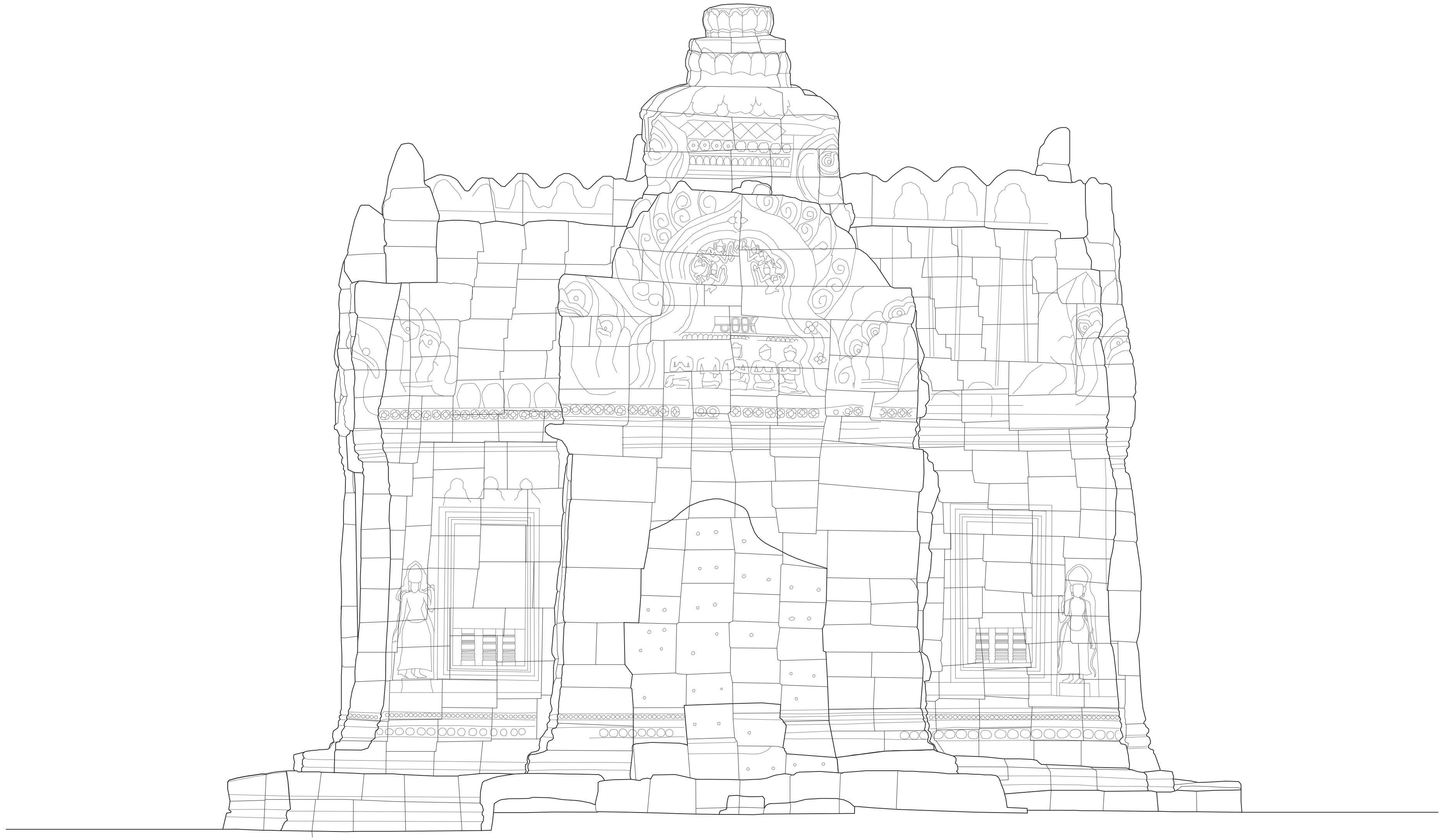
04-2. South elevation after restoration S=1:50

05-1. West elevation after restoration　S=1:50

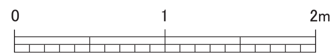
05-2. West elevation after restoration S=1:50



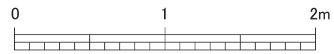
06-1. North elevation after restoration S=1:50

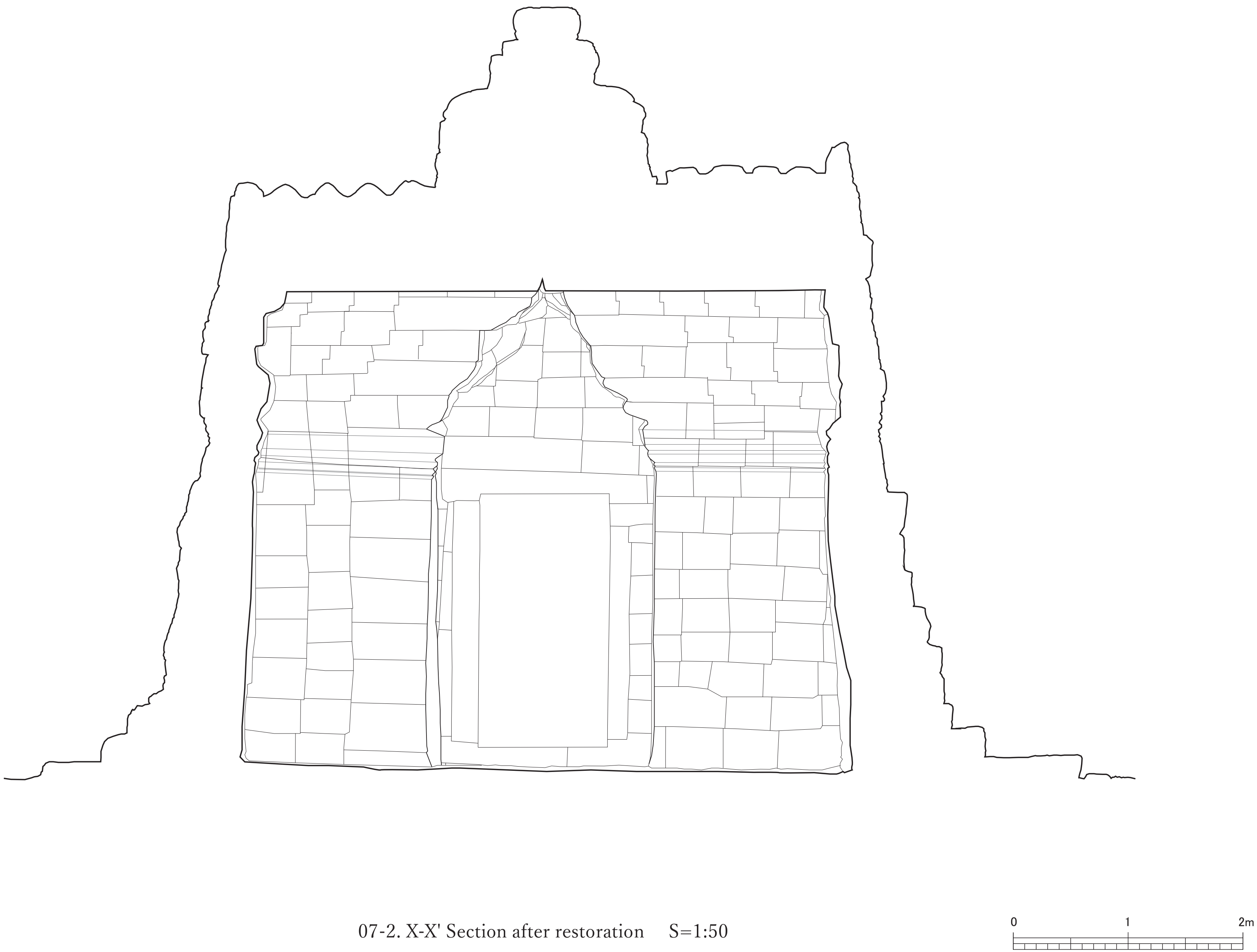


06-2. North elevation after restoration S=1:50



07-1. X-X' Section after restoration S=1:50





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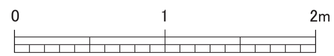
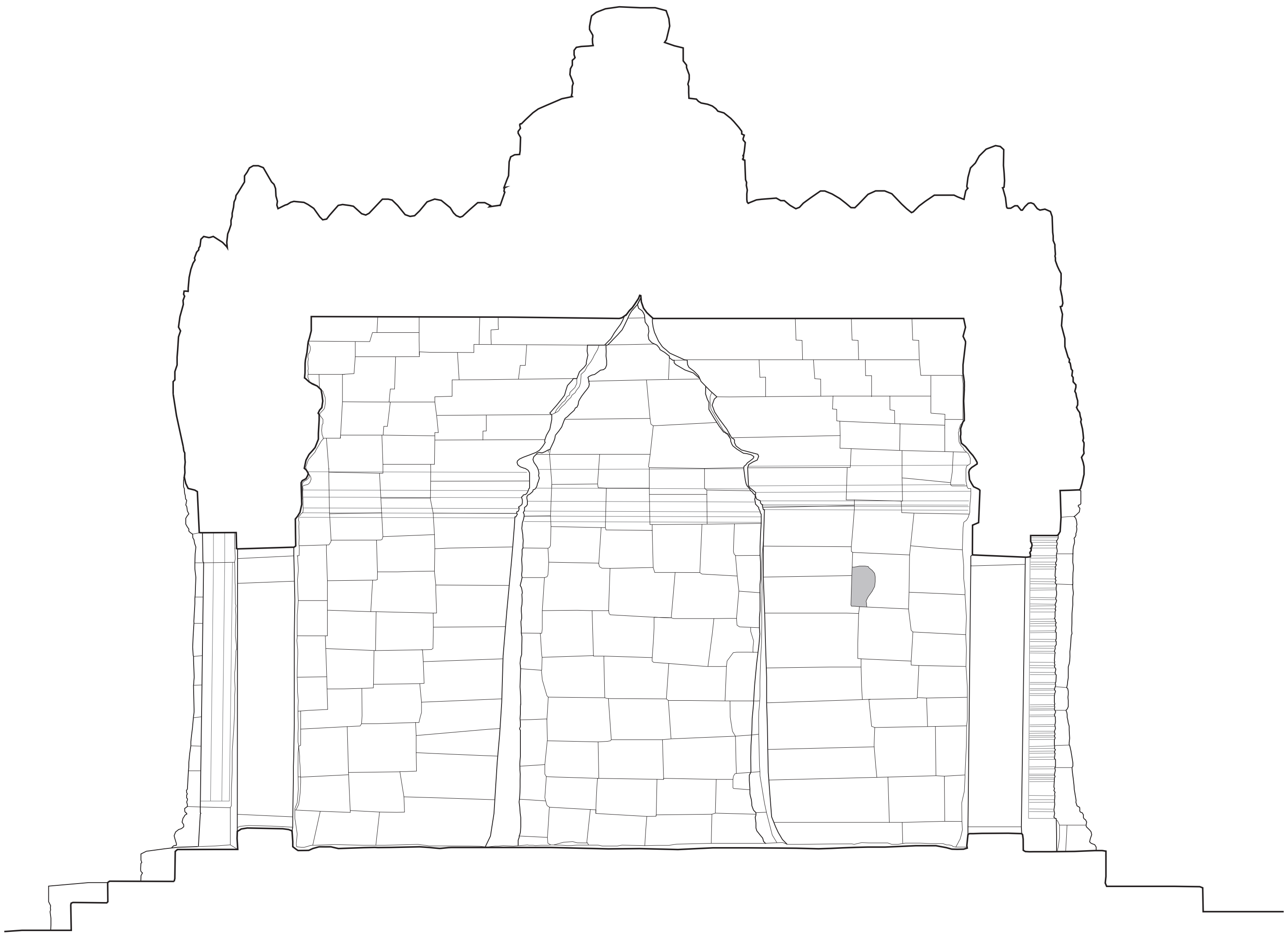
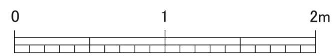


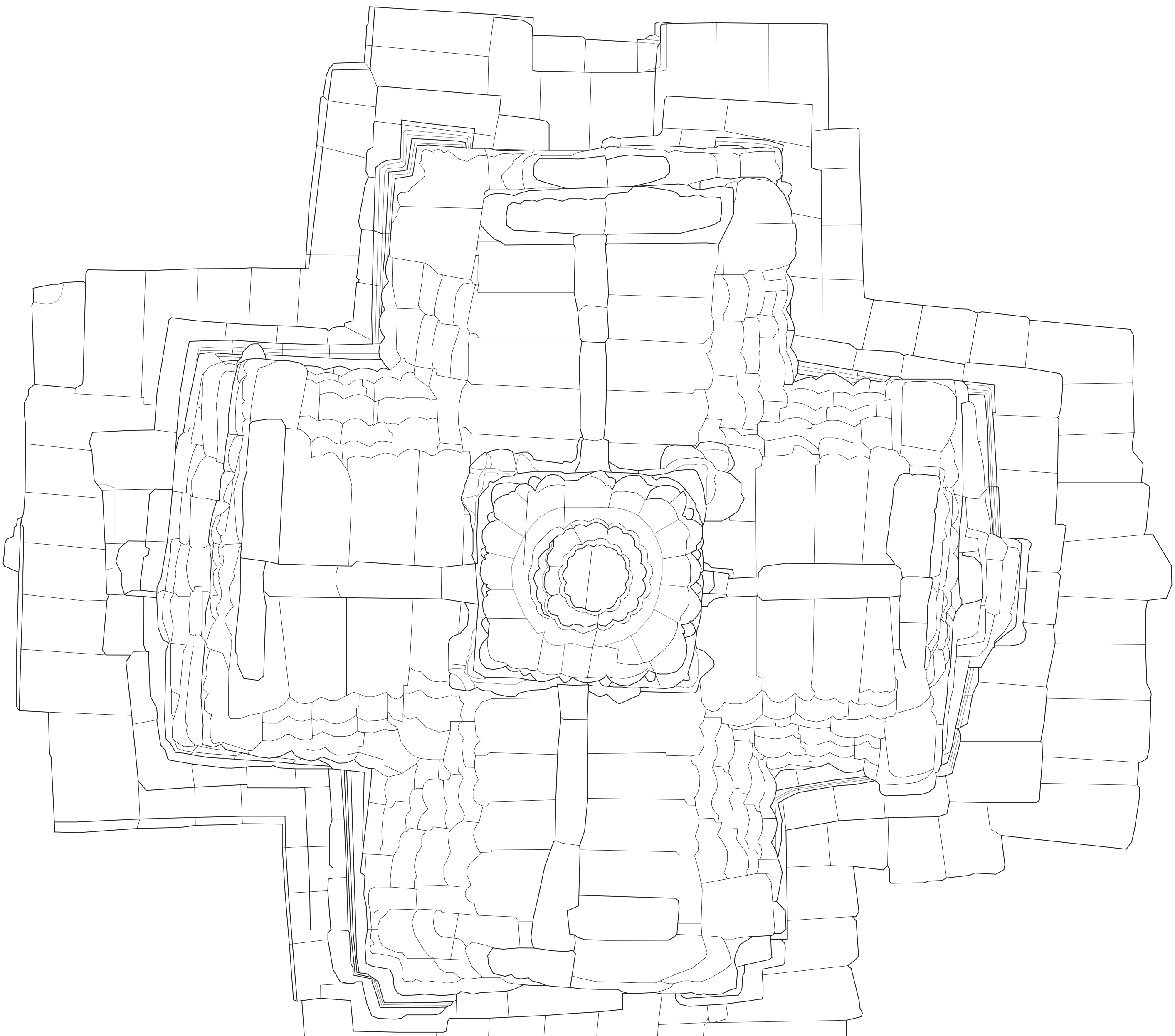
08-1. Y-Y' Section after restoration S=1:50



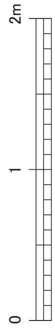
08-2. Y-Y' Section after restoration S=1:50

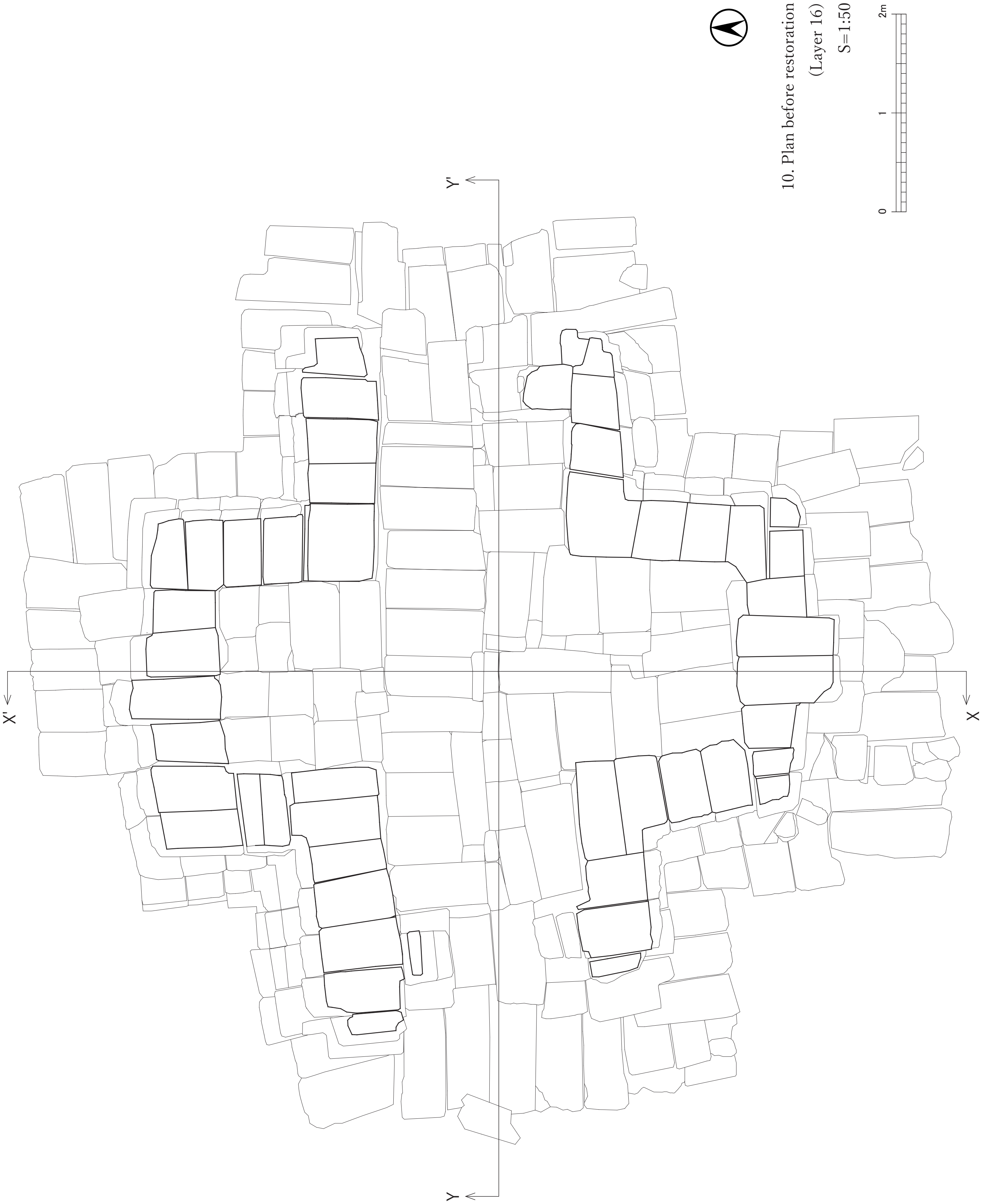


09-1. Roof plan after restoration
(Layer 16)
S=1:50

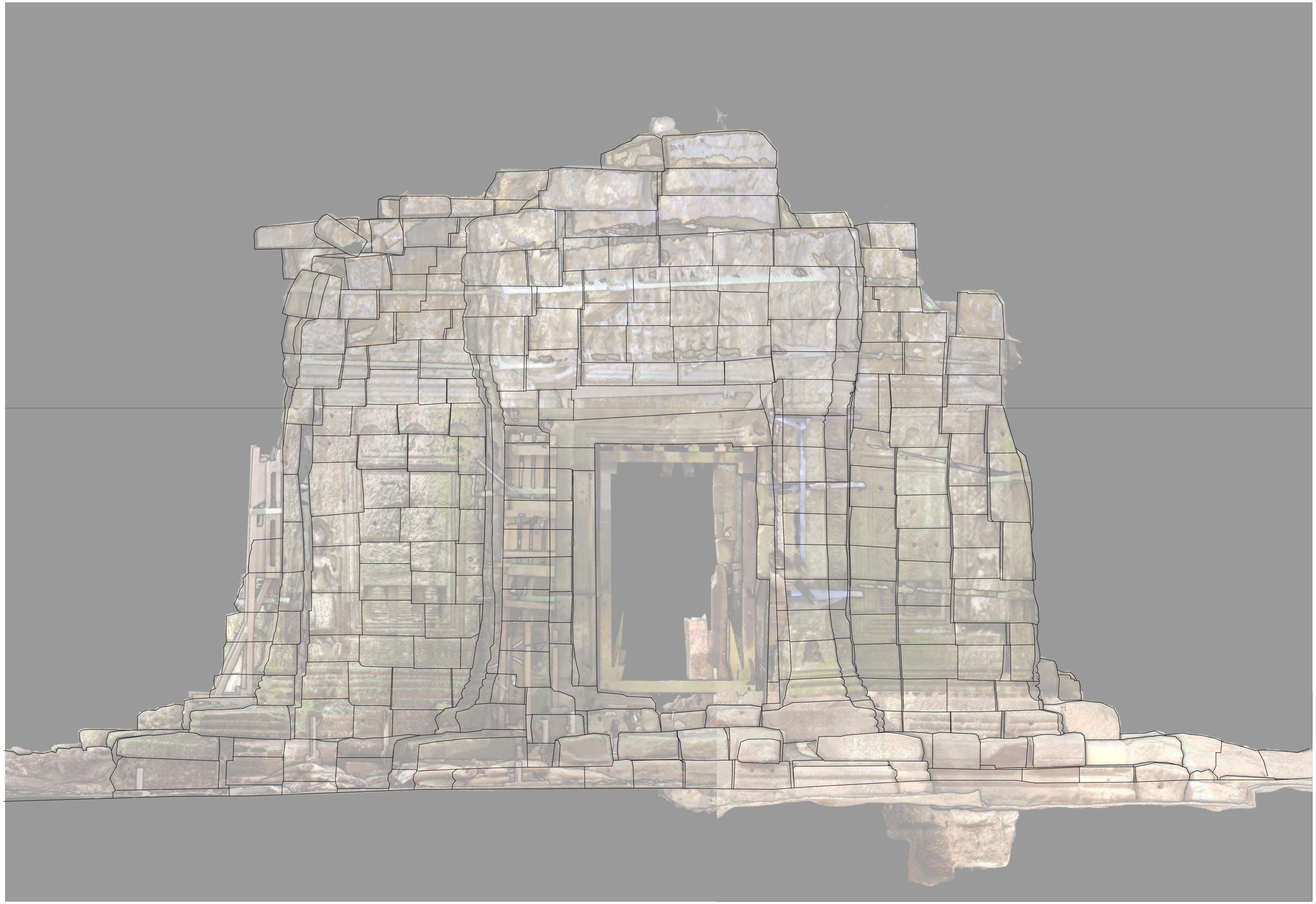


09-2. Roof plan after restoration
(Layer 16)
S=1:50

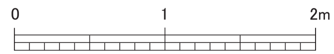


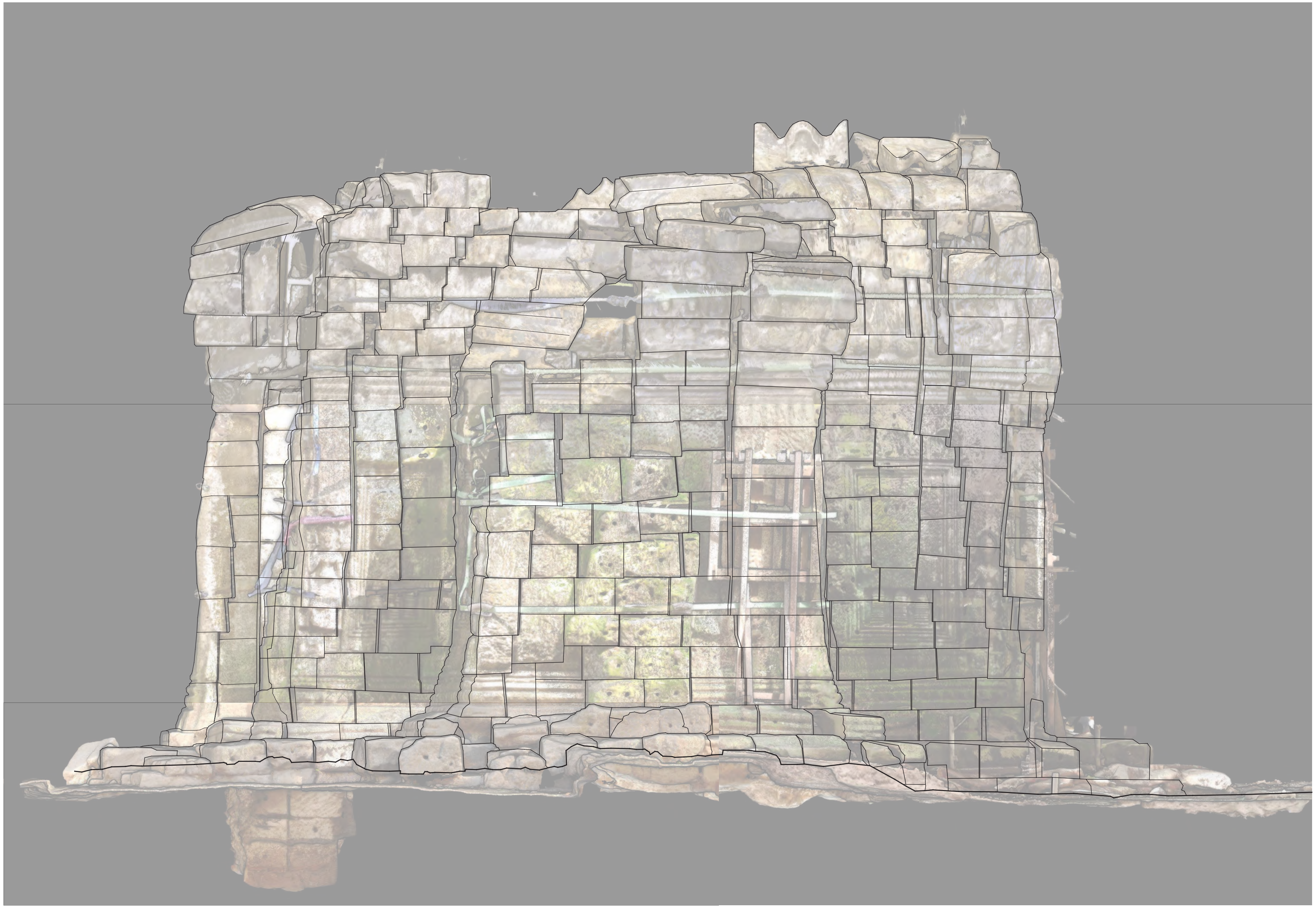


10. Plan before restoration
(Layer 16)
S=1:50

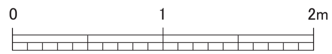


11. East elevation before restoration　S=1:50

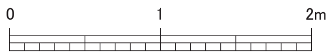


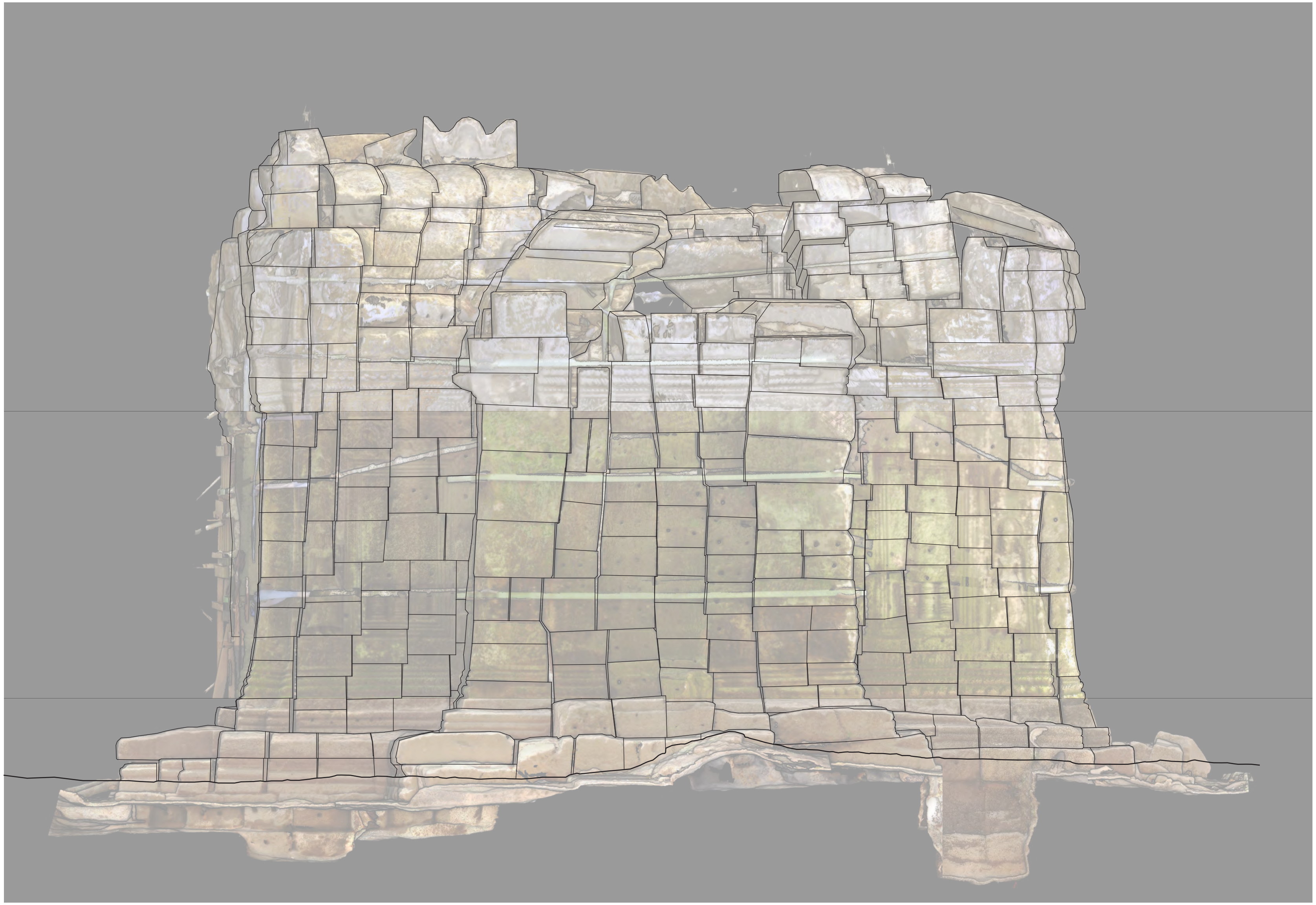


12. South elevation before restoration S=1:50

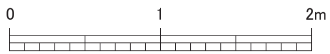


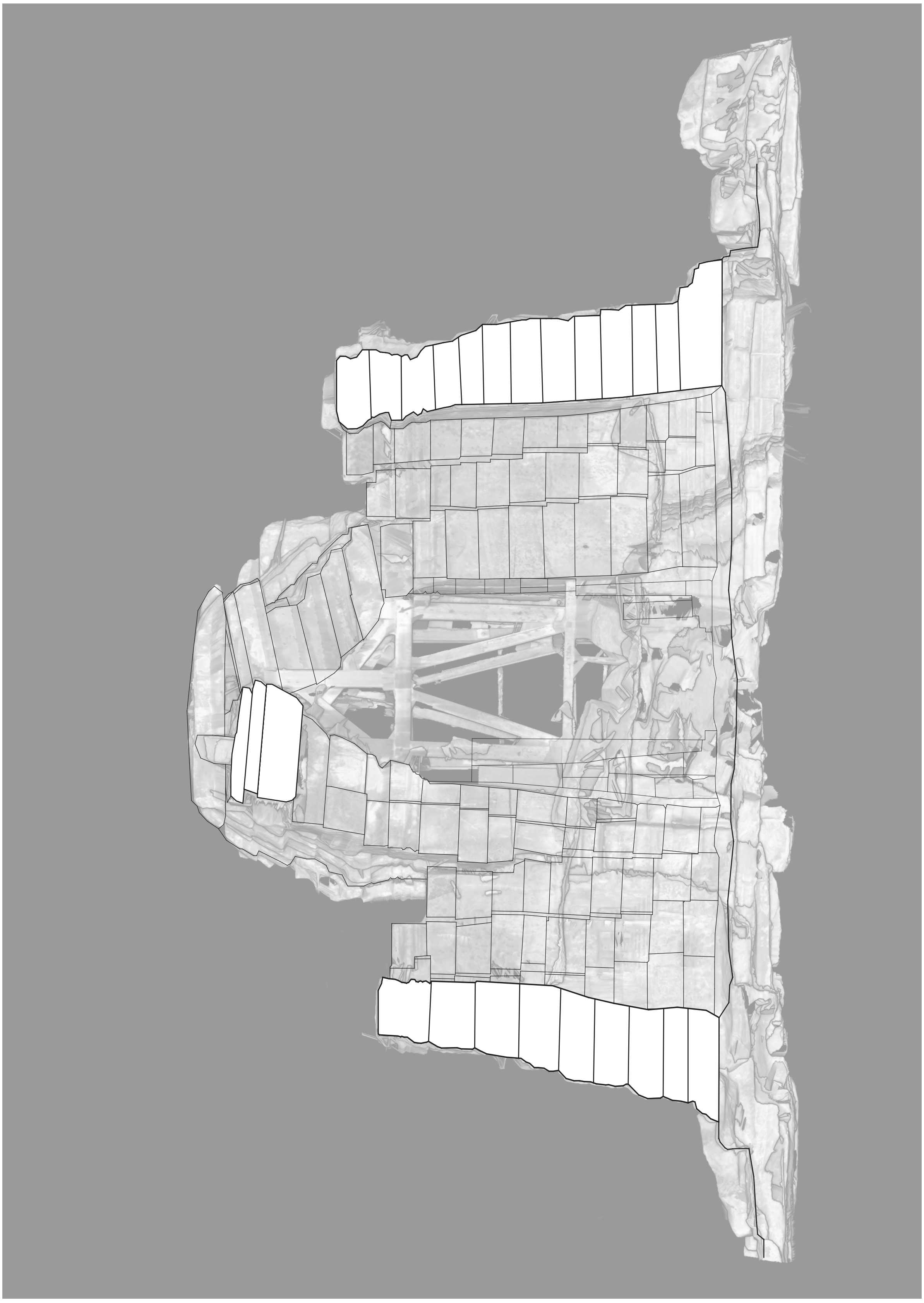
13. West elevation before restoration　S=1:50

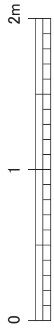




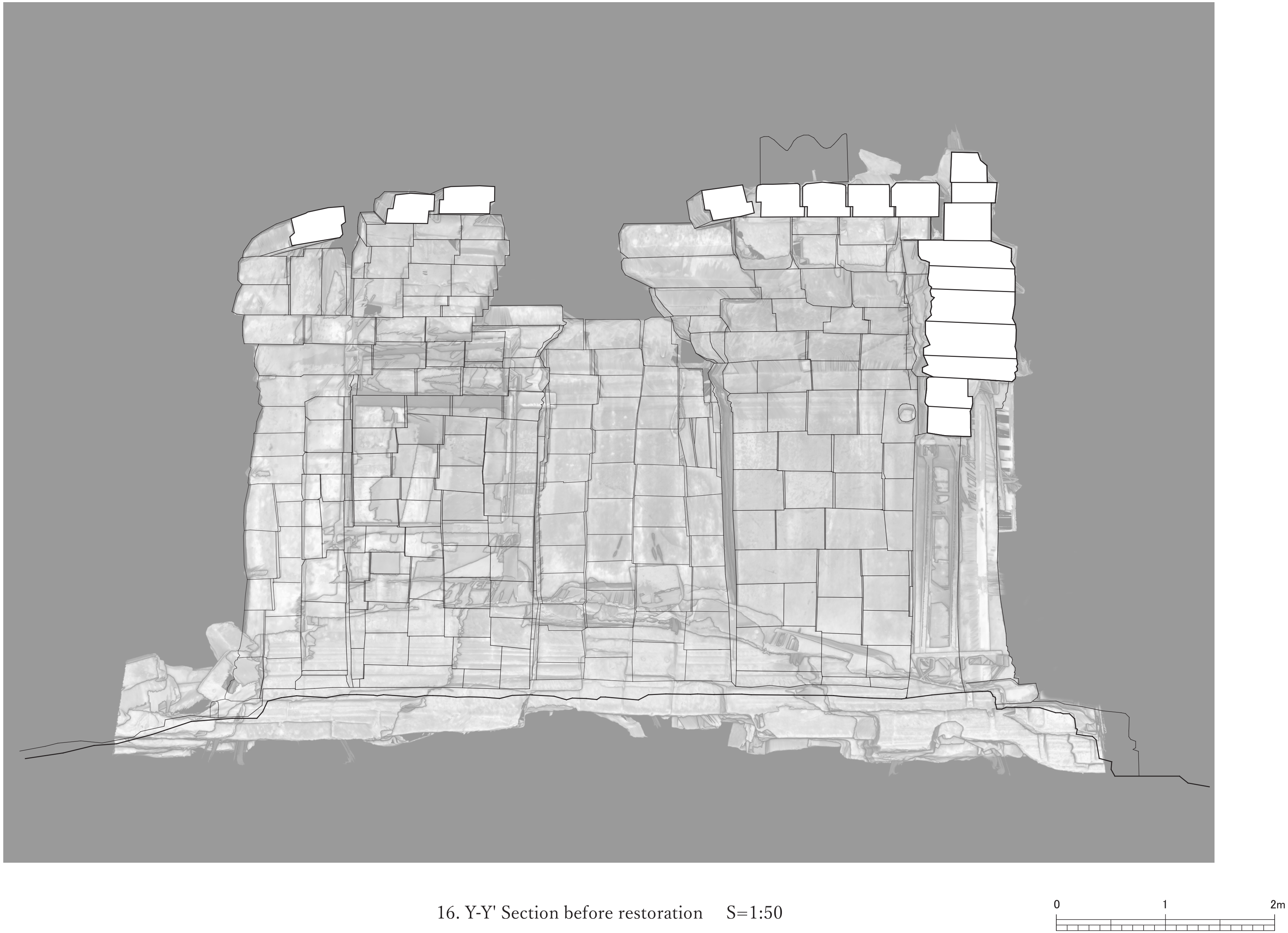
14. North elevation before restoration S=1:50



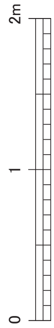




15. X-X' Section before restoration S=1:50



16. Y-Y' Section before restoration S=1:50



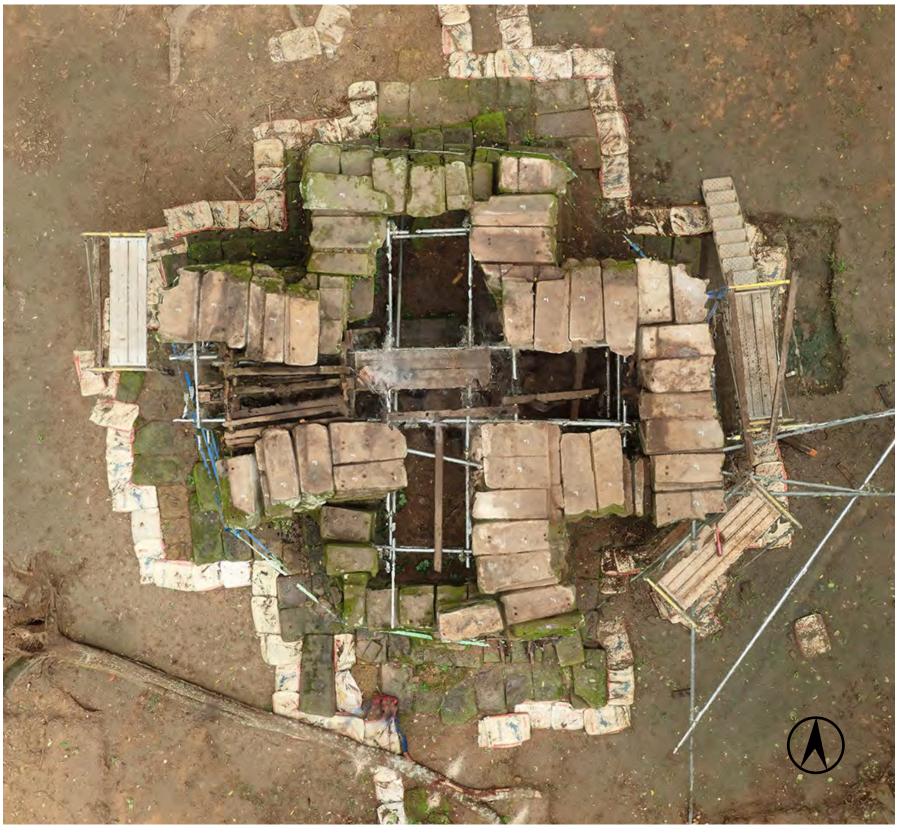
17. Ceiling plan before restoration
(Layer 16)
S=1:50

18. Plan during dismantlement (Layer 00)

19. Plan during dismantlement (Layer 01)

20. Plan during dismantlement (Layer 02)

21. Plan during dismantlement (Layer 03)


22. Plan during dismantlement (Layer 04)


23. Plan during dismantlement (Layer 05)

24. Plan during dismantlement (Layer 06)

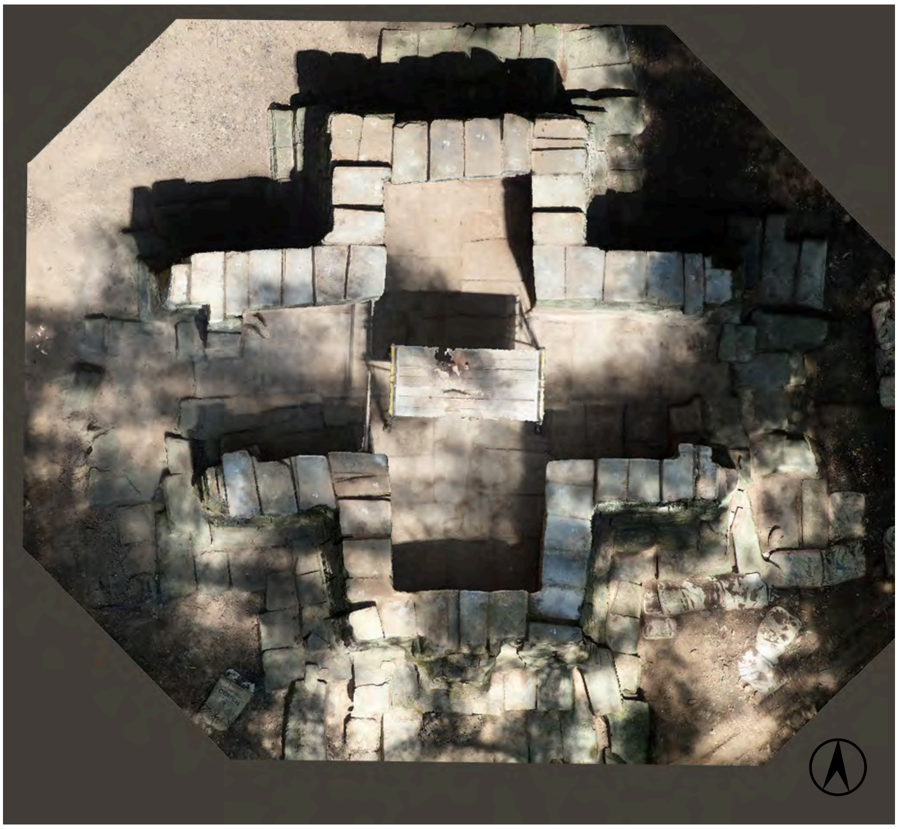
25. Plan during dismantlement (Layer 07)

26. Plan during dismantlement (Layer 08)

27. Plan during dismantlement (Layer 09)

28. Plan during dismantlement (Layer 10)

29. Plan during dismantlement (Layer 11)



30. Plan during dismantlement (Layer 12)

31. Plan during dismantlement (Layer 13)

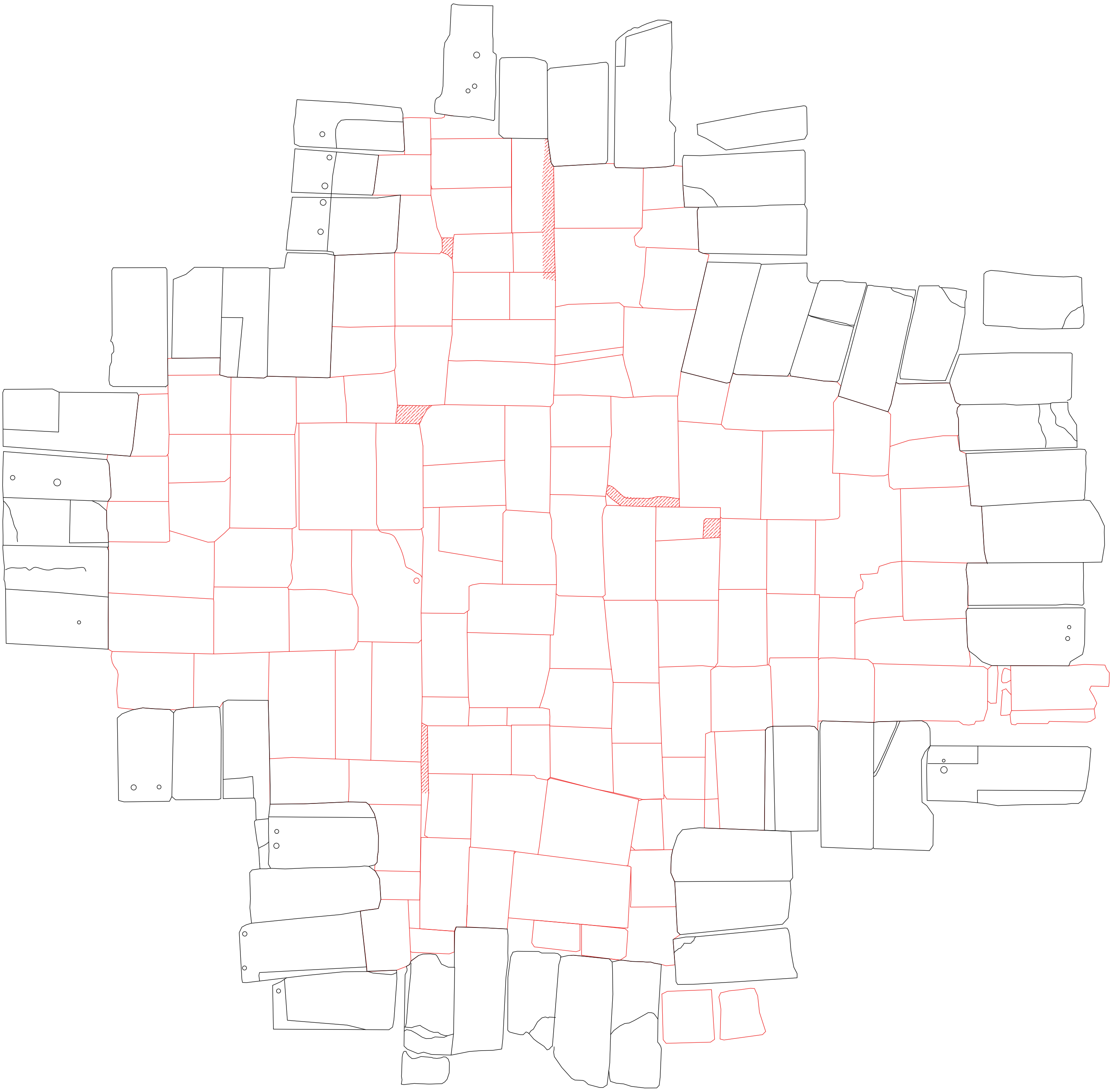

32. Plan during dismantlement (Layer 14)


33. Plan during dismantlement (Layer 15)

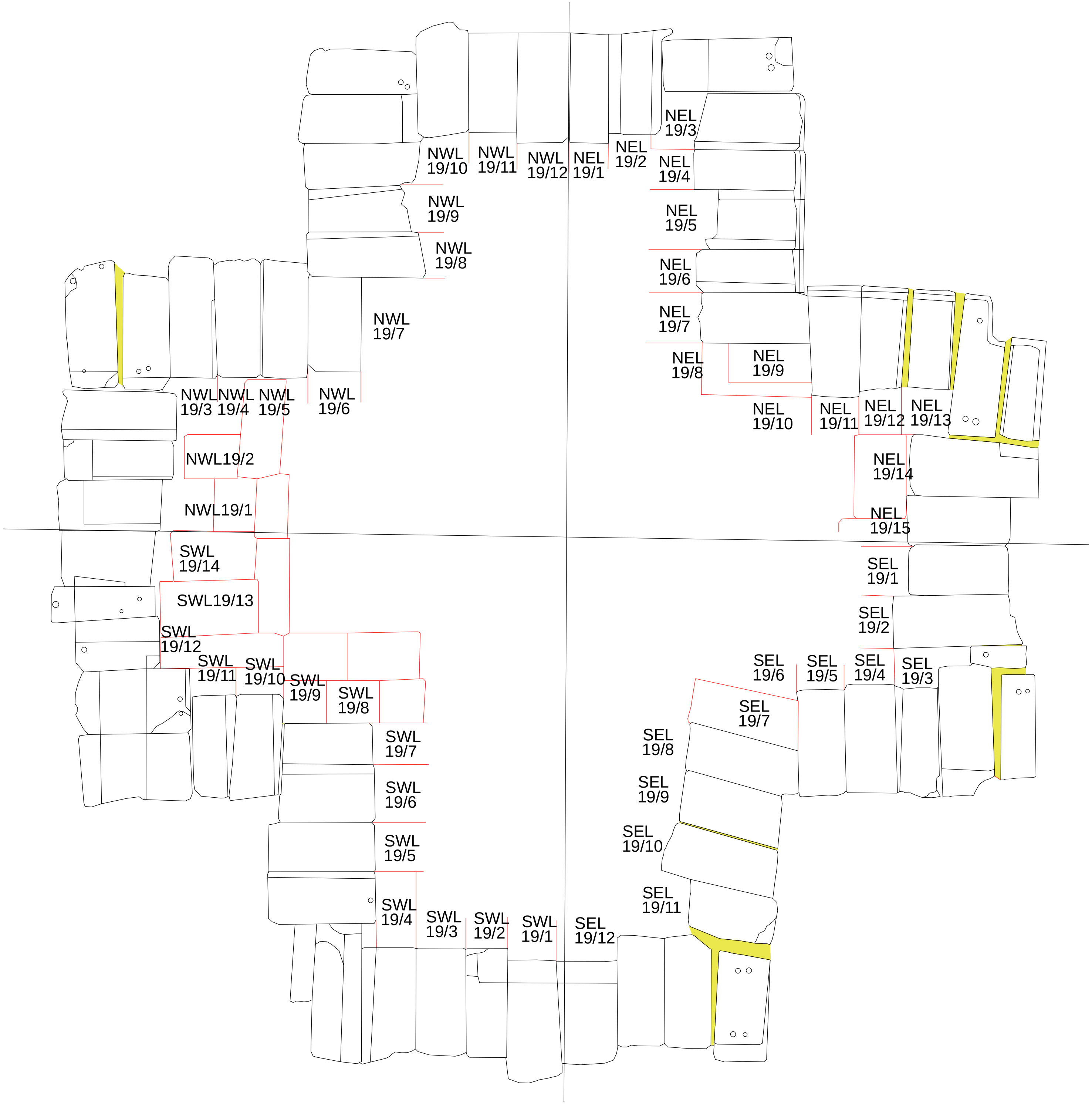
34. Plan during dismantlement (Layer 16)

35. Plan during dismantlement (Layer 17)

36. Plan during dismantlement (Layer 18)



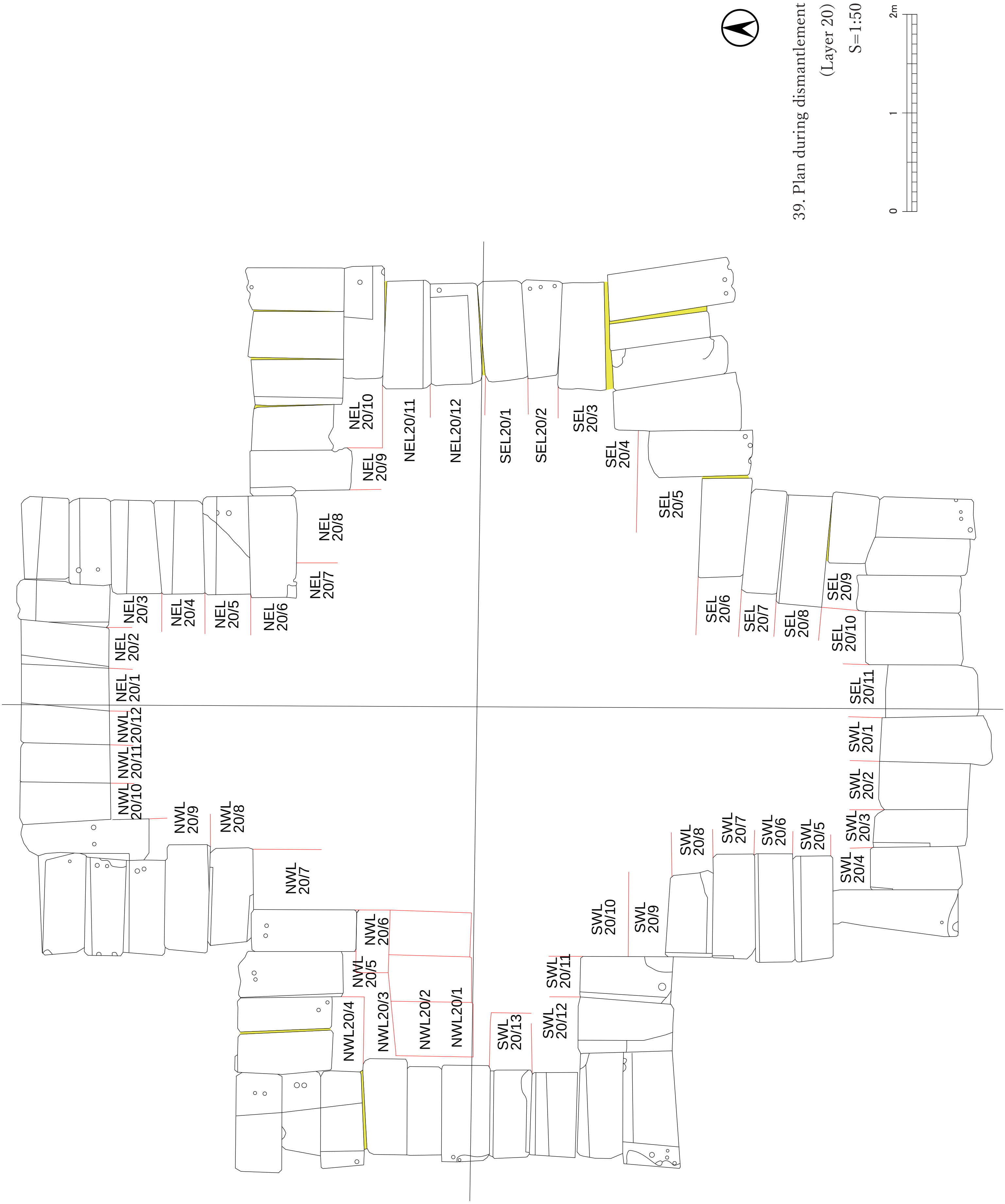
37. Plan during dismantlement
(Layer 18)
S=1:50



38. Plan during dismantlement

(Layer 19)

S=1:50



39. Plan during dismantlement (Layer 20)

S=1:50