THE EAST AND SOUTH ENTRY TOWERS OF CHAU SAY TEVODA RESTORATION DESIGN DESCRIPTION

Chinese Government Team for Safeguarding Angkor

Section One: Restoration Design of the East Entry Tower

1. General Survey of the East Entry Tower

1.1 Architectural Form and Structure

The East Entry Tower is the front gate of Chau Say Tevoda. It is cruciform in shape, has a width of 16.6 meters and a depth of 11.4 meters, and comprises three passageways. (The other three entry towers all have only one passageway.) The central passageway goes through a large cruciform hall, with a porch on both the front, the back and two side rooms. The porches to the east and west and the side rooms to the south and north all have windows with balusters. Two square passage halls are connected to the central hall through the south and north passageways. Each passage hall has two doors facing each other, and a third door opening onto a side room of the central hall (Figure 1).

Figure 1. West Elevation of the East Entry Tower.

The East Entry Tower is built on a 1.77m-high platform. The four outer sides of the platform are of sandstone masonry. The tower itself consists of plinth, frieze and upper layers or "eaves." The inner walls of the platform are built with laterite blocks. The whole base is sculpted with a decor of scrolls, lotus and pellets, etc. The walls, 40~50cm thick, constitute a structure of simply laid and piled sandstone blocks polished on six faces. No bonding agent was used. The staggered joints are of no strict regularity. The outside face of the walls is sculpted with lotus reliefs. There is richly carved decor on the upper levels. The roof is of arch construction. After the collapse of the roof arch stones, small red bricks were once used to repair the roof; some remaining red bricks can still be seen on the roof of the north passageway. A square vault rises above the central passageway.

Originally, there were 12 sets of different pediments on the East Entry Tower. Research and tests conducted by French archaeologists showed that, among those pediments left, at least 2 sets depict scenes from the Mahabharata and most carvings on the other pediments depict Shivaite and Vishnuite themes. These are precious materials for studying the history and sculptural art of Chau Say Tevoda.

1.2 Survey and Analysis of Causes of Damage

Most of the masonry stones of the platform have been dislocated, especially those of the east porch and the south passageway. The platform itself has subsided, with the masonry becoming loose and deformed, and components falling off. (Figure 2).

Figure 2. Eastern Entrance Platform of East Entry Tower.

The roof and south sidewall of the east porch have long collapsed. The joint of the remaining north sidewall and the main wall also show upright cracks. The eave stones have become loose.

Pediments and some roof arch stones of the west porch have collapsed. Both the south and the north sidewalls tilt to the west.

The southeast corner area of the central hall has subsided by 10cm. The southeast corner and the south side-room of the central hall each have a major vertical crack running from top to bottom; the wall has settled, its foundation smashed and windows broken; the window lintels are dislocated by 7cm.

The south and north inner partition walls of the central hall have collapsed. The door lintel and the inner eave above it have also long collapsed, and the remaining doorframe is seriously deformed and tilting. In order to avoid further collapse of the vault of the central hall, in earlier restoration work, a cast-in-place concrete beam was put in over the door lintel to support the upper suspended wall. At the same time, a reinforced concrete lintel was used to replace the rotted wooden lintel.

The whole south passageway is tilting to the southeast. The pediments and roof arch stones over the east and west entries have collapsed, the door stone has subsided and caused the doorframe to tilt inward (Figure 3).

Figure 3. West Entry of South Passageway of East Entry Tower.

On the southwest corner area of the south side-room of the central hall, there is a big long 10~20cm-wide crack, running straight from top to bottom. Two upright cracks of 2~4cm in width also appear on the east wall of the north side-room of the central hall.

The roof of the vault has collapsed and there is a straight crack on both the south and north walls. The latter is 20cm wide and has split the vault in half.

The causes of such serious damage to the East Entry Tower are complex. In structural terms, we should point out the fatal combination of a heavy roof and a weak foundation. The East Entry Tower is built on an approximately 5m-deep layer of fine- medium grained sand. The foundation of the whole construction is based on this sand layer. According to analyses of the construction method of the foundation, the depth of the foundation of the East Entry Tower could not have exceeded the thickness of two laterite blocks (around 60cm). On the outer surface of the laterite foundation, there is a thin façade of sandstone, while the interior of the foundation is sand and soil backfill. Calculated according to simple analysis of the central hall, the bearing capacity of the foundation soil cannot possibly meet the needs required of the load above it. In addition, other reasons such as tree roots

penetrating the construction and splitting it open, ants and other insect disturbance, the backfill not being solid enough, etc. all aggravated foundation subsidence, causing tilting and deformation of the walls as well as the collapse of the roof (Figure 4).

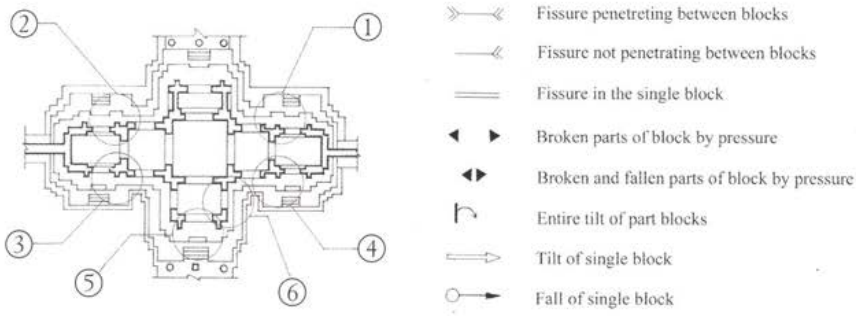
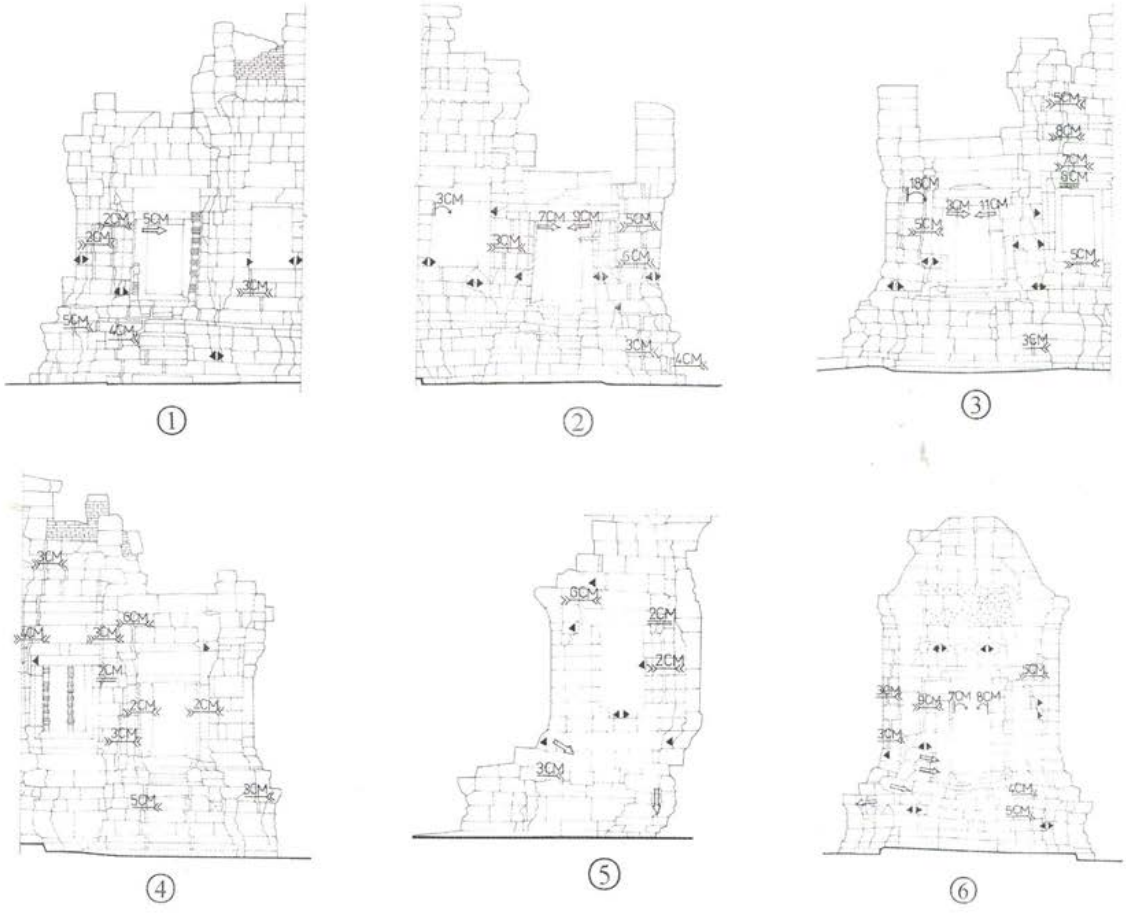


Figure 4. Damage to East Entry Tower.



1.3 Emergency Protection and Consolidation Work on the East Entry Tower in the Early 20th Century

Following is relevant information recorded in the Reports of the Conservation of Angkor.

January 1919. "The pediments on the west entry porch of the East Entry Tower have become rather loose, and flat iron bars were used to wrap the pediments."

July 1926. "After the south area of the room at the far south of the East Entry Tower was thoroughly cleared, we successfully reinstated the southeast corner layer by layer. The pediment on this wall which was on the point of collapse was also restored."

May 1927. "Restored the stone blocks at the southeast corner which had become seriously dislocated." However, "in most cases, we should not aim to restore these dislocated structures to perfect condition." The platform of the porch of the east entry "has subsided more seriously and the crack on the joint is more serious, too. This was caused by the invasion of tree roots."

June 1927. "A huge tree stump was cleared out of the East Entry Tower. This stump had been blocking the entry."

April 1937. "Due to the break of the 32×6mm flat iron hoop, the pediment at the west entry collapsed on April 10th. The pediment was either fractured or smashed to a certain degree and the collapse has overturned and squashed some taller circular columns in the passageway."

2. Restoration Projects for the East Entry Tower and Basic Requirements of Restoration

2.1 Restoration of the Platform

We aim to place those seriously subsided and dislocated stone blocks back in their original positions, to reinstate missing elements and destroyed components and to ensure proper drainage and seepage prevention.

2.2 Restoration of Porches at the East and West Entries of the Central Passageway

To put back fallen pediments, doors, windows, walls etc. into their original positions, and to completely reinstate the missing components of walls, doors, windows, wall columns and roof.

2.3 Restoration of the Central Hall and the South and North Siderooms

To repair walls of the southeast corner area of the central hall and the east and west walls of the south side room, to restore doorframes, door lintels and inner eaves leading to the south and north siderooms, and to restore the east walls, the west walls and the doorway.

2.4 Restoration of the South Passageway

To repair the east walls, the west walls and the gable, and to correct deformation of the building.

2.5 Restoration of the Vault

To consolidate the cracks on the south and north walls of the vault.

3. Technical Design for Restoration of the East Entry Tower

3.1 General Requirements of Restoration Work

The current state of the East Entry Tower requires partial dismantling before rebuilding. Detailed and concrete analysis needs to be done on the subsidence, crack and dislocation of the building. Given the stability of the building structure, the dismantling should be limited to a strict minimum so as to avoid damage to building components.

Initial survey of those collapsed components of the East Entry Tower allowed for identification of elements such as pediments over the east and west porches, and wall columns of the east porch and windows. Discoveries were also made of the arch stones of the east and west porch roof. Therefore, basic requirements for restoration work is defined as "Emergency Protection and Consolidation and Restoration with Priorities." After restoration, different dangers threatening the East Entry Tower will be eliminated; most fallen components will be reassembled and put back to their original positions. The East Entry Tower will be once again sound, stable and appear intact.

3.2 Extent of Dismantling

The restoration project will dismantle and rebuild the following parts: the vault and the south side room of the central hall, the south passageway and the east porch. Dismantling thus concerns 50% of the total components of the East Entry Tower.

3.3 Methods for Foundation Consolidation

3.3.1 Consolidation Methods for the Foundation of the Dismantled and Rebuilt Parts

After removing the original soil, a 24cm-thick bedding cushion of 3:7 lime-earth mix is to be laid (rammed in three layers). The elevation of the upper surface of the lime soil is 0.3m below the exterior floor level. Above the lime-earth, laterite blocks will be used for the foundation in accordance with the original construction method.

3.3.2 Indoor Water Drainage Methods

In conjunction with foundation consolidation, a cement pipe of 15cm in diameter is to be embedded beneath the indoor floors of the central hall, the east porch, the south side room and the south passageway porch. The lower ends of the cement pipes will pass through collecting wells and horizontal pipes (internal diameter 20cm), and drain rainwater into permeable wells.

3.3.3 Consolidation Methods for Indoor Backfill Soil

Dig out all the indoor backfill soil and sift, remove roots, weeds and other things, then add 30% clay and about 10% lime powder and mix them well. Finally, ram layer by layer.

3.3.4 Restoration Methods for the Platform and Tower Base

We aim to dismantle and rebuild the platform and the tower base of the south passageway, the south side room and the east porch, lined inside with laterite blocks. Those laterite blocks that have weathered and are broken are to be replaced with newly mined laterite blocks. The sandstone façade blocks will be repaired and consolidated when possible; missing blocks will be replaced with new stone materials of similar texture.

As for the remaining parts of the platform and tower base, partial digging and replacement of missing elements will serve to correct deformation.

3.4 Restoration Methods for Pediments, Lintels, Doorframes and Wall Columns

Among the 12 sets of pediments of the East Entry Tower, only 2 sets from the north passageway, and 2 other sets from the south gable and the north gable, remain intact; the other 8 sets have all collapsed. The pediments of the east and the west porches have been found. Further information still needs to be gathered for the remaining pediment elements. Missing pediment components that have no effect on the stability of the whole structure will not be reinstated for the mere purpose of completion. For instance, the flame acanthus and dragon head etc. around the pediment do not need to be recreated if missing.

The lintel, at the front of the entry gate, is the most characteristic building component of Angkorian monuments. Two octagonal stone columns are set under the lintel. These stand on each side of the door, functioning as support to the lintel. At the East Entry Tower, there are a total of 6 exterior doors, 6 interior doors and 20 octagonal columns. Out of the 20 octagonal columns, 8 remain and 12 are missing. The broken columns are repaired and consolidated and then put back to use. The missing ones are replaced by new stone materials. The elaborate sculptural decor of these columns is not imitated, instead, these are simply remade in similar size and shape.

The door columns and wall columns are all used as bearing components for upper construction support. Missing parts shall therefore be reinstated with stone materials of similar texture and according to original size and general style.

3.5 Roof Repair Methods

The five arch roofs of the East Entry Tower have all collapsed; only a few arch stones remain on the roof of the south and the north side rooms. In addition, some red bricks, once used to restore the roof after the arch construction collapsed, are scattered around the north side room and the north passageway. Brick barrel-vault roof construction is another traditional construction method used at Angkor, seen for example on the two libraries of Banteay Srei, the East Entry Tower of the Royal Palace, the entry tower of Ta Keo, etc. The red bricks remaining in Chau Say Tevoda, however, were added in later times during restoration work.

Restoration at present aims to maintain the actual condition. That is to say that the missing arch stones are not to be reinstated with new stone materials; the remaining red bricks are to be shown partially according to original building methods and no missing elements will be reinstated.

4. Restoration Plan for the East Entry Tower

The first stage of work consists in undertaking careful and detailed survey and mapping, along with photographing and videotaping the East Entry Tower in order to establish documentation on the present state of the building. For components to be dismantled, numbered plan drawings in layers are made; the actual components are discreetly numbered with white paint.

These are dismantled according to the following order: vault of the central hall; south passageway; south side room of the central hall; east porch.

Restoration and consolidation are carried out according to the following order: consolidate the foundation and restore the platform; indoor drainage work; wash, clean, restore and consolidate the components; match and reassemble the components; restore the 4 doorways and the inner eave of the central hall; replace components dismantled from the south side room to their original positions; replace

components of the south passageway to their original positions; restore the east porch; restore the west porch; replace components dismantled from the vault to their original positions.

Schedule for Restoration of the East Entry Tower

No	Work Items	Months of Year 2001											
		1	2	3	4	5	6	7	8	9	10	11	12
1	Component Dismantling	■											
2	Foundation Consolidation		■										
3	Platform Restoration			■									
4	Indoor Water Drainage		■										
5	Component Clearing, Repair and Consolidation	■	■	■									
6	Component Matching & Reassembling			■	■	■							
7	Central Hall Restoration				■	■							
8	South Side Room Consolidation						■	■					
9	South Passageway Consolidation								■	■			
10	East Porch Consolidation										■	■	
11	West Porch Consolidation											■	■

Section Two: Description of Design on the Restoration Project of the South Entry Tower

1. General Survey of the South Entry Tower

1.1 Architectural Form and Structure

The South Entry Tower is cruciform in shape, with a width of 12m and a depth of 9.6m. It faces north and has only one passageway. The windowed face is the front gate. The passageway goes through a cruciform central hall. There is also one door on the south face of the hall and there are 4 filled-in windows in each of the left and right side rooms (Figure 5).

The platform of the South Entry tower is about 90cm in height. Stairways are built at the south and north entry. It joins the enclosing wall at its east and west ends. The four sides of the platform are in sandstone masonry forming the tower base. The interior of the platform consists in inner walls built with laterite blocks, and a backfill of fine sand and soil. The sculpted decor of the base is similar to that of the East Entry Tower. However, the structure of walls of the two entry towers are different. The walls of the East Entry Tower are built wholly with huge stone blocks, with elaborate sculpture on the outside walls, while the walls of the South Entry Tower are built with two different materials. The surface of the walls is made of about 26cm-thick unpolished and unsculpted sandstone blocks. The inner walls are built with laterite blocks, each about 15cm thick. However, the laterite walls are only 1.8m high, above which the sandstone walls stand alone.

Figure 5. North Elevation of the South Entry Tower.

Analysis of the existing structure, in conjunction with matching and reassembling collapsed components, allows us to hypothesize that before collapse the South Entry Tower consisted in a vault built over the porch; the roof of side rooms were stepped; and each had sets of pediments (Figure 6).

1.2 Survey and Analysis of Causes of Damage

The South Entry Tower is seriously damaged. With the exception of the platform that is still relatively complete, most of the roofs have collapsed, leaving only broken walls. The vault of the central hall and the roof of the north entry porch have collapsed. The remaining walls of the east and west side rooms and of the south entry are also seriously tilted and deformed: the south wall of the east side room is tilting inward by 17cm; the west wall of the south entry is tilting eastward by 15cm. The doorframe, lintel and pilasters, etc. at the south entry have therefore broken, cracked or collapsed. A vertical crack of 10 ~ 16cm in width appears at the southeast corner of the central hall.

Analyses and tests have been carried out to uncover the causes of such serious deterioration of the South Entry Tower. These have included hole drilling

Figure 6. South Entry Tower.

to expose the strata, Light Dynamic Detection Test and Light Static Detection Test in situ, extracting undisturbed soil samples, obtaining dynamic parameters of the foundation soil through Rayleigh Wave Test and Micro-tremor Test, surveys of the geological conditions for construction and hydrology of the foundation soil, along with environmental investigations. Results show that the causes of deterioration fall into the following two major categories.

First, we have a problem of building structure. The foundation of the main structure above the base is a strip foundation. However, the main structure was built by simply piling up stone blocks. No bonding agent was used and the piling of the stone blocks was irregular, in stark contrast to traditional Chinese construction methods of staggered-joint bond. For this reason, the integrity of the building is poor, causing the foundation's upper load to be unevenly distributed. The platform composed of sand and soil, and laterite and sandstone blocks shoulders the upper load. However, the gradation of the sand and soil fill inside the tower base is poor, its relative density being low. A field test showed the bearing capacity to be only between 0.1~0.3Mpa. As a result, the stability and balance of the building depend only on the weight of stones and the frictional force between stones, contending with lateral pressure produced by the main building load. Therefore, the insufficient strength of certain parts of the base has decidedly contributed to the uneven subsidence of the building itself.

The second major cause of deterioration is nature. Tropical rain forest areas are characterized by large woody plants and insects which reproduce rapidly. The effects that tree root cleavage, biological activity, rainfall and strong winds have on buildings are obvious. Long-term effects of these on the building structure and the density of the foundation are disastrous.

From 1925 to 1927, a French archaeology team conducted clearance work, together with emergency protection and consolidation of the South Entry Tower. They discovered "many intact bricks and stones, as well as the head, arms and feet of a female divinity. " They "opened up an inner door in a low wall of the South Entry Tower, which was built with lime mortar and stone blocks." They "also put in a bracing member in a blocked up window in the east area"(Figure 7).

2. Technical Design of Restoration of the South Entry Tower

2.1 General Ideas on the Restoration

The roofing and most walls of the South Entry Tower have collapsed. Those remaining walls and porches are themselves tilted and deformed and could collapse any minute. For this reason, restoration work on the South Entry Tower should include "Emergency Protection and Consolidation" as well as "Restoration with Priorities." Those seriously deformed structures should be dismantled and rebuilt. These include damaged walls of the east wing and the west wing, the porch of the south entry and the southwest corner area of the platform, etc.

Restoration priority is given to the following: walls below eaves, windows, platform, and roofs of the east and west wings and pediments of the central hall. So far, more than a hundred components fallen from walls, blocked up windows, eaves etc. have been discovered. After restoration, not only should the South Entry Tower no longer be in danger, but it should appear better intact, with the fallen components back in their original positions. We estimate that, with the exception of the vault of the central hall and the roof of the south and the north entry porches, the structure could be restored to varying degrees.

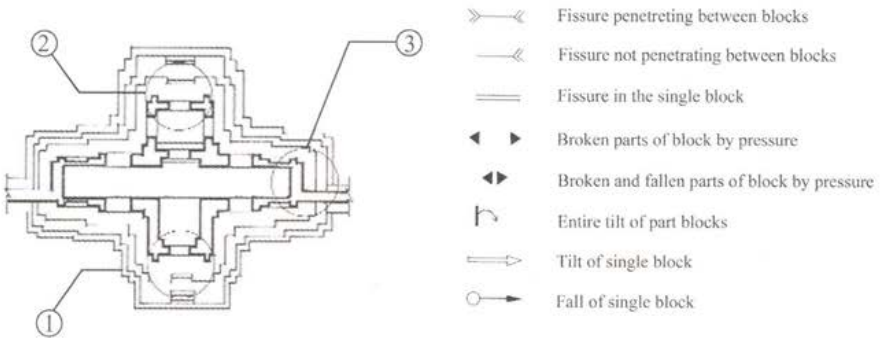
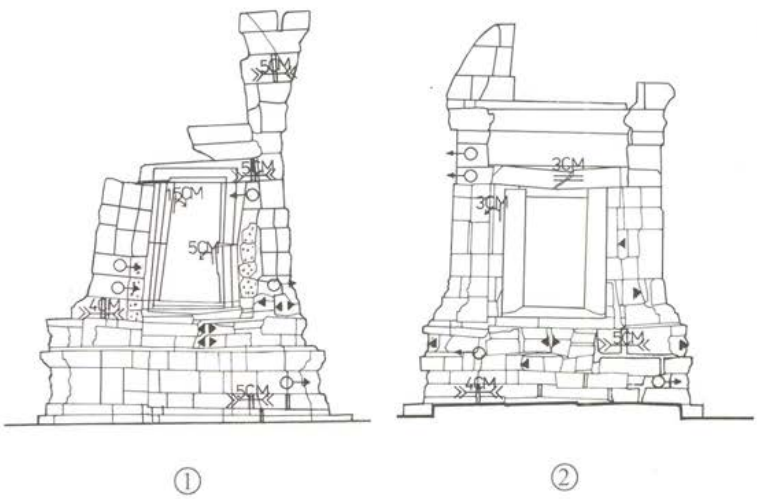


Figure 4. Damage to South Entry Tower

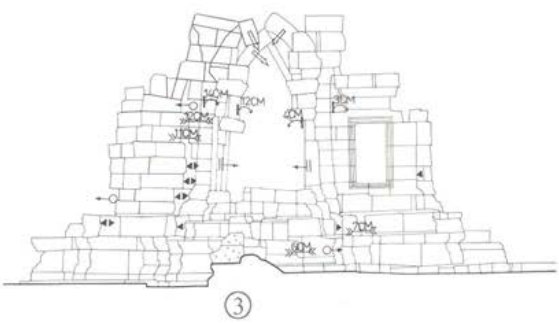
2.2 Restoration of the Platform

2.2.1 Consolidation of the Backfill Soil inside the Platform

The hole-drilling detection test, along the tower base under the platform, showed a layer of 30cm-thick laterite blocks. Underneath this is a fine sand and medium sand layer measuring 0.7m in depth. Still lower is a silty soil sand layer 1.9m deep. The backfill used inside the platform is of fine and medium grained sand.



Consolidation of the backfill inside the platform is done in conjunction with indoor water drainage pipe work. Consolidation consists in adding 30% clay and lime powder (10% of the amount of clay) into the original sand, stirring and mixing well, and then ramming in layers.



2.2.2 Methods for Foundation Consolidation

After dismantlement of the wall components of the east and west wings and the porch of the south entry, the foundation is to be carefully examined to determine the construction method used and its current state of preservation. If the foundation is the same as that of the Southern Library, i.e. there is only one layer of laterite blocks and it has already subsided and become deformed, then the embedded depth of the foundation must be increased according to the design requirements, laying a 3:7 lime earth mix bedding cushion.

Experience proves that when the compacting factor of the 3:7 lime earth mix bedding cushion is controlled at 0.97 and the dry soil weight no lighter than 14.5~15.0KN/m3, bearing pressure can reach 0.3Mpa under the condition that the particle diameter of lime is no larger than 5mm, of the soil no larger

than 15mm and that the percentage of cultivated soil, swelling soil and organic matter is less than 8%.

2.2.3 Restoration Methods for the Tower Base

The method used in building the base of the South Entry Tower is the same as that used for the Southern Library: a thin façade of sandstone blocks is applied to the outside face of the laterite blocks. That the decorative sandstone and the laterite blocks are not connected by bonding agents or iron leads to serious dislocation of the outer sandstone layer. Therefore, these dislocated stones are to be reinstated in conjunction with consolidation work on the foundation.

2.3 Indoor Water Drainage Work

A set of concealed drainage pipes is to be embedded beneath the indoor porch floors of the north entry and the central hall. The rainwater will be channeled into a permeable well through the concealed pipes.

2.4 Restoration of the Walls and Roofs

2.4.1 Dismantling Range of the Components

The whole porch at the south entry, the south wall of the east wing, the east part of the north wall of the east wing and the whole west wing need to be dismantled and rebuilt. Proper measures must be taken during dismantling to avoid damaging the sculptures. Repair and consolidation plans are to be made for the various dismantled components, according to the degree of damage.

2.4.2 Matching Collapsed Components

The matching of collapsed components is a fundamental task of restoration work. First, we try to gather as thoroughly as possible elements of walls, wall columns, door lintels, eaves, etc. Restoration plans, including the quantity of components to be reinstated, are to be based on this work, so as to avoid embarrassing situations in which original components are discovered after others have been reinstated.

Matching on site and partial matching on the restoration platform are combined. Partial matching for parts such as pediments, wall columns and arch stones is to be conducted on the restoration platform. General, final matching is to be completed on site.

2.4.3 Reassembling Components

The reassembling of components is to be done after the platform and indoor drainage work is finished. Before final on-site matching, those components to be reinstated should be identified as well, and initial consolidation measures should be taken. Detailed treatment is carried out during final reassembling.

For the positions of cast iron tenons used for connecting components, the original settings of tenon-and-mortise work are to be maintained in principle. Damaged joints can be repaired by deepening the mortise and adding epoxy resin. The T-shaped cast iron tenon is laid into the mortise, and the surface then sealed with epoxy resin.

2.4.4 Restoration Method for the Roof

The work of organizing and matching collapsed components has shown that many elements are missing from the roof of the four wings of the central hall and from the upper vault. Any attempt to reestablish the building's original state would require the introduction of many new materials. We have tentatively decided that the roofs of the east wing and the west wing and the platform of the vault are to be restored first. Restoration of the remaining parts of the structure are to be decided upon further organizing and matching of the collapsed components.

3. Restoration Plan for the South Entry Tower

3.1 Construction Procedures for Restoration of the South Entry Tower

3.1.1 Recording the Present State

Before restoration, the present state of the South Entry Tower must be recorded carefully in great detail. This includes producing survey drawings, photos and videotapes.

3.1.2 Matching Components

Components fallen from the eaves, the base of the vault and arch stones from some roofs are to be matched on site to locate their respective positions before dismantlement. Components fallen from other parts of the building such as pediments and vaults should also be matched in groups before dismantling. In short, for restoration of the South Entry Tower, we must clearly establish accurate positions and quantity of collapsed components, identification of the missing elements and their positions, as well as a detailed plan for replacing or reinstating components before any dismantling is conducted.

3.1.3 Dismantling Components

Before components are dismantled, numbered plan drawings in layers and blocks are to be made. All dismantled components must also be numbered. The dismantling should be conducted in layers, proceeding from top to bottom. Dismantled components are to be placed in order in groups.

Schedule for Restoration of the South Entry Tower

No	Work Items	Months of Year 2001											
		1	2	3	4	5	6	7	8	9	10	11	12
1	Component Matching												
2	Component Dismantling												
3	Indoor Water Drainage												
4	Foundation Consolidation & Platform Restoration												
5	Component Clearing, Repairing and Reinstating												
6	Component Installation												