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Structural defects and solutions: A case study of Fort Cornwallis, Penang, Malaysia

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Abstract

Fort Cornwallis, which was built in 1810, has a significant role in the history of Penang Island, Malaysia. Gazetted in 1977 under the Antiquities Act 1976, the Fort is considered as an important monument and landmark in the historical development of Malaysia. In March 2000, the Malaysian Government through the Department of Museums and Antiquity had granted a total sum of RM2.1 million (US$0.5 million) for the restoration of the Fort Cornwallis. The project was carried out in two stages. The first stage included building defects diagnoses, structural analysis, application of proven conservation methods and techniques as well as recording and documentation. Stage two included the reconstruction of the demolished Fort's west wall. This paper focuses on some major structural defects of the Fort Cornwallis and some methods and techniques used in handling the building defects. It also discusses some issues and problems related to the project.

1 Introduction

Located at the northeastern tip of Penang Island, Malaysia, the Fort Cornwallis is considered as an important monument and landmark in the historical development of Malaysia. Due to its historical values, the Malaysian Government had gazetted the Fort in March 1977 under the Antiquities Act 1976 for the purposes of conservation and preservation. In March 2000, a total sum of RM2.1 million had been allocated by the Malaysian Government through the Department of Museums and Antiquity to carry out restoration project of the Fort Cornwallis. Restoration works were carried out over a period of one year and was completed in March 2001. To assist and monitor the project progress, a team

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of consultants including structural engineer and conservation consultant were appointed by the government. Other professionals including quantity surveyor, archaeologist, microbiologist, geologist and electrical engineer were also engaged in providing expert advise on specific methods and techniques employed during the project.

2 Historical background

Upon taking possession of the Penang Island from the Sultan of Kedah in 1786, British Captain Sir Francis Light built the Fort Cornwallis covering an area of 417.6 ft^2 [1]. The Fort was originally built with a *nibong* (palm trunk) stockade with no permanent structures. However, it was rebuilt in 1804 with bricks and stones by Indian convict labour during Colonel R. T. Farquhar's term as Governor of Penang. It was later completed in 1810 during Norman Macalister's term as Governor of Penang at the cost of $80,000 [2]. It covers an area of 332,859 ft^2. A moat of 9m wide and 2m deep was built around the Fort but later had been filled in due to the malaria epidemic in the 1920's. Historical accounts including survey maps, old photographs and records of the Fort Cornwallis have shown that the star-shaped Fort was filled with buildings and structures including military barracks and offices as well as a gunpowder magazine, a Christian chapel, a harbour light, flagstaff, cannons, cell rooms, a store and guard houses. Some of these structures are still survived and are found to be structurally sound. The harbour light was used to signal incoming ships while the flagstaff was used to announce the arrival of mail ships or the decent of the Governor and other dignitaries from the Penang Hill [3].

In its entire history, the Fort had never been engaged in any battle. Its function was more administrative rather than defence. It has lost much of its importance when Penang changed its position from a military base to civil administration in 1898 [4]. During the 1920's, the Fort had been occupied by the Sikh Police of the Straits Settlements. The Fort has lost some of its original structures except the gunpowder magazine, a Christian chapel, cell rooms, flagstaff, harbour light and several cannons. It has double walls (outer and inner walls) on all its 4 sides (north, east, south and west zones). However, in the early 1970's, the double walls on the west zone including the main entrance were demolished to give way for the city sewerage systems and electrical equipments. Instead, an iron fence and gate were placed along the west zone. In the early 1970's, several additional structures had been erected inside the Fort Cornwallis including a modern amphitheatre, souvenir shop and toilets to promote cultural activities and heritage tourism. Since then the Fort has become a popular destination among the local and foreign tourists.

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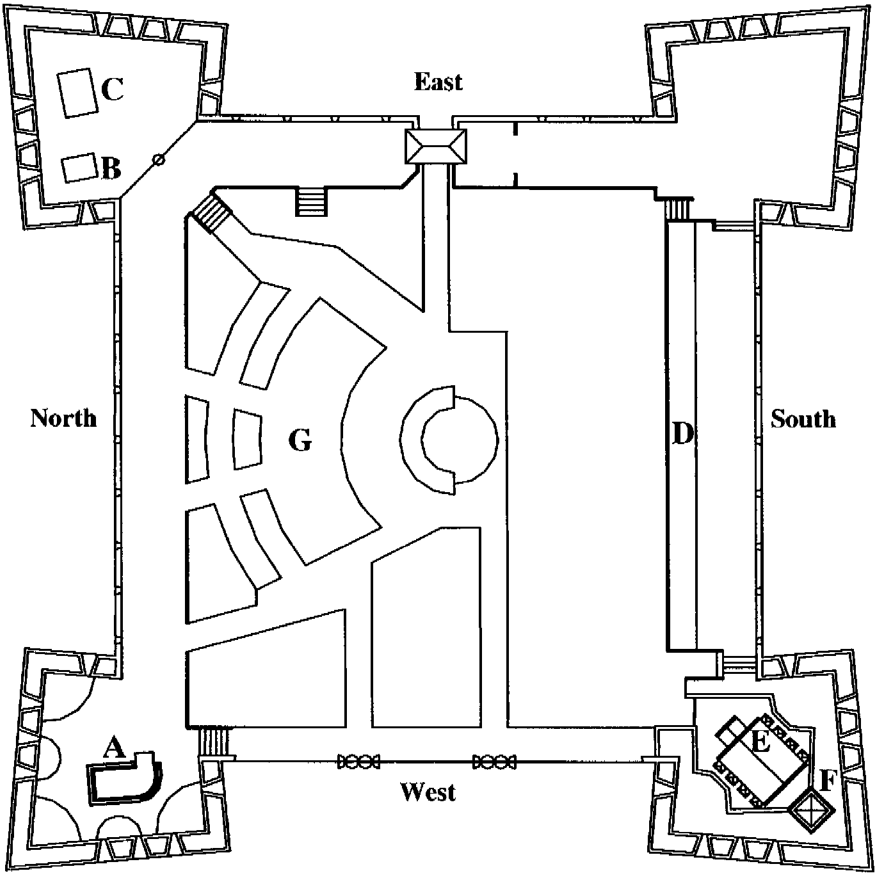

Legend:
A – Gunpowder magazine
B – Flagstaff
C – Harbour light
D – Cell rooms
E – Chapel
F – Store
G – Amphitheatre

N

Scale 1 : 600

Figure 1: The floor plan of the Fort Cornwallis (before restoration) showing the four zones of its walls and the locations of some of the original structures (A, B, C, D, E and F). The amphitheatre (G) was built in early 70's.

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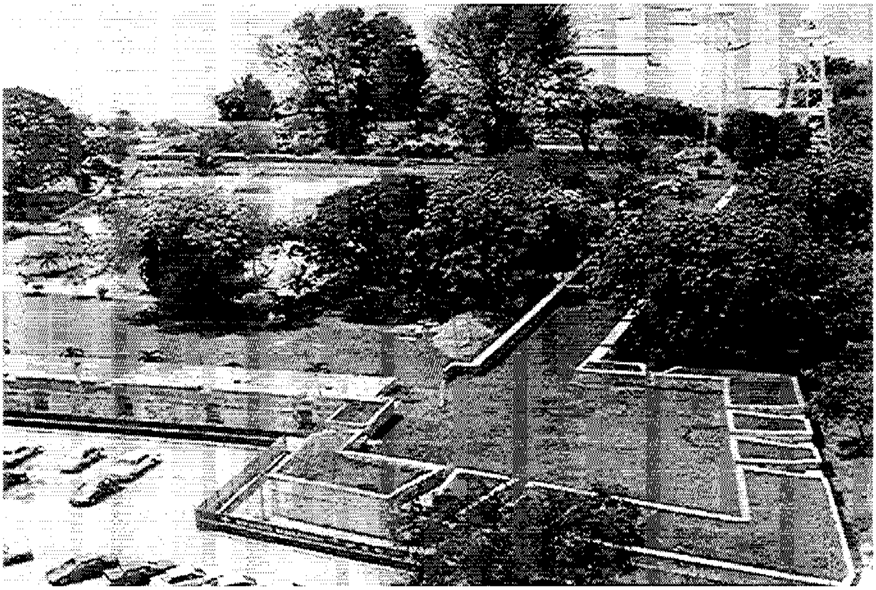

Figure 2: An aerial view of the Fort Cornwallis (during its restoration work) showing one of its double-walled corners as well as the flagstaff and harbour light at the upper right.

3 Structural defects of Fort Cornwallis

In the early stage of restoration project of the Fort Cornwallis, dilapidation surveys were carried out in order to identify structural defects, their locations and possible causes. Some of the major structural defects discovered at the Fort were cracks, leaning walls and collapsed walls [5].

Cracks, either major or fine, were common defects found at the Fort Cornwallis. Major cracks were found on the top of the south zone's wall and more obvious at the corners of the wall whereas fine cracks were found mostly on wall surfaces and rooftops of the Christian chapel. Structural investigations showed that these cracks were caused by local settlement, water pressure, microorganism growth and erosion of mortar joints as well as constant traffic vibrations. Major cracks were also found to have related to broken brickworks that were caused by weak structures or poor mortar joints. Wall surfaces were also affected by erosion of mortar joints which was caused by air pollution and the growth of microorganism.

Some parts of the Fort's walls were found to have leaned or collapsed. These structural defects were caused by several factors including soil movement, presence of dampness, water pressure or constant traffic vibrations from the surrounding roads. Apart from cracks, leaning walls seemed to be another common structural defects at the Fort. Leaning walls were found at the south and

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north zones mainly at double-walled corners. As the result, major cracks had occurred at these affected walls. Due to the conditions of the leaning walls, the earth filled in between the double walls were found to be sagged and uneven. On the other hand, collapsed walls were found mostly on the top of the walls located at both east and north zones of the Fort. Apart from the existing walls that had been leaned or collapsed, the demolished walls at the west zone were also taken into account as one of the structural defects of the Fort Cornwallis. Reconstruction of the walls at the west zone was carried out to bring back the Fort to its original shape.

4 Structural analyses

Based on the structural defects identified on the Fort Cornwallis, a few structural analyses were conducted on existing building materials and structures in order to identify their components and strength respectively [6]. The structural analyses involved were X-ray fluorescence (XRF) analysis, compressive strength tests and foundation load tests. Results gained from structural analyses of existing building materials and structures were formulated to rectify such structural defects.

4.1 X-ray fluorescence (XRF) analysis

The X-ray fluorescence (XRF) analysis involved a total of 9 samples of the existing building materials namely old mortar joints, cement top and wall plaster. The purpose of this XRF analysis was to analyse the components of these materials. Results of the analysis had shown that the samples had relatively high content of SiO_2 and CaO of which helped in preparation of a mixture with appropriate proportions of lime plaster, fine sand and red clay that matched the existing building materials. The closest possible mixtures that matched the existing mortar joints, cement top and wall plaster were used to rectify any structural defects.

4.2 Compressive strength tests of red clay bricks

Most of the old red clay bricks used on the Fort's walls were handmade and were of different sizes. The old bricks measured between 20.3cm and 24.7cm in length and between 9.0cm to 12.7cm in width. Several compressive strength tests were carried out on selected brick samples taken from each side of the Fort's walls in order to ascertain the strength of the existing red clay bricks. The test results had shown that the compressive strength of the Fort's clay bricks were mostly higher compared to Malaysia's normal standard of clay brick compressive strength which is 14 N/mm^2 (Figure 3).

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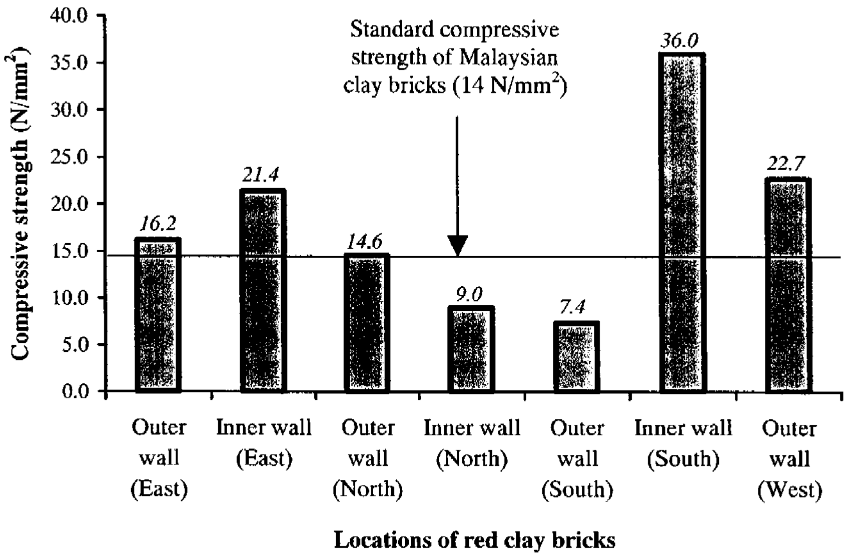

Figure 3: Compressive strength of the old red clay bricks at Fort Cornwallis.

4.3 Foundation load tests

The purpose of the foundation load tests was to validate the strength of the remaining structures found at the west zone after the excavation work so that any rectifications such as reconstruction activity on the existing foundations could be undertaken. As the walls on the west site of the Fort have been demolished earlier, several load tests on the remaining structures mainly the wall foundations were carried out for the purpose of reconstructing the demolished walls. Six different points of load testing were identified along the existing wall foundations to ensure their strength in supporting the load of the new walls. The true load bearing capacity was derived from the loading of the existing walls by measuring the area of the walls and the block's self weight. The maximum test load was maintained for 24 hours and time-settlement reading was continuously monitored and recorded. Loading was released gradually and the rebound readings were later taken. Throughout the excavation works, the old Fort's foundations were found embedded about 1.5m beneath the ground. Results showed that the total residual settlement taken from 6 different load tests ranged between 0.7mm and 3.36mm. Example of the load test results taken from one of the six identified locations is shown in Figure 4. Failure shall be considered when the total residual settlement after removal of the test loads exceeds 6.5mm or the total settlement under the design load exceeds 12.5mm. Results from the load tests indicated that the foundations of the west zone walls were structurally sound and capable of supporting any new wall structures.

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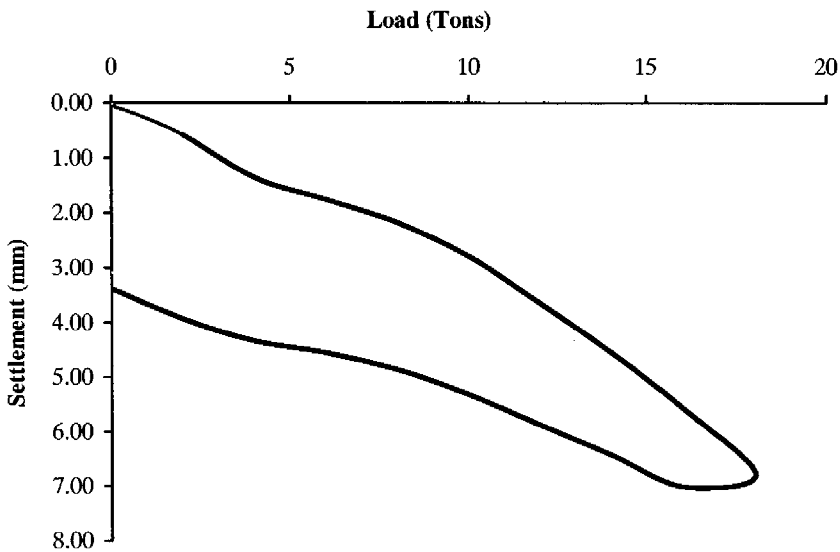

Figure 4: Results of the foundation load tests from one of the six identified locations.

5 Solutions for structural defects

There were several methods and techniques adopted to rectify structural defects of the Fort Cornwallis [7].

5.1 Major and fine cracks

Fine cracks on walls surfaces and rooftops were rectified by pouring a mixture of lime plaster and water into the cracks using Peter Cox's method. Such method required the use of an empty bottle that has rubber tube underneath. Upon placing the mixture into the bottle, the rubber tube would be inserted onto any fine cracks to allow the mixture to flow and fill up any capillaries or fine holes in the wall structures or rooftops mainly at the Christian chapel.

For major cracks which involved broken brickworks, the brickworks were carefully removed and replaced to reinstate to their original positions. In the case of weathered or crumbly mortar joints, re-pointing method had been undertaken. Such re-pointing of mortar joints was carried out by raking out the decayed mortar joint at the depth of between 25mm and 40mm followed by refilling the joint with the closest possible mixture of lime-sand-red clay mortar which was prepared based on the results derived from the X-ray fluorescence (XRF) analysis.

5.2 Leaning walls

In order to reinstate the leaning walls into their original position, the wall jacking method was used. This is in view of minimum disturbance to the walls' structures. The first step taken in this method was removing 60-75cm depth of earth behind the leaning wall while raking shores were used to provide temporary support to the leaning wall. This was followed by several 10cm-diameter of hand drilled concrete piles at about 25cm intervals behind the leaning walls. The walls were later pushed and jacked gradually to their original positions before filling the empty trench behind the leaning walls with earth. Once the walls were reinstated to their original positions, a few new weepholes were fixed at the lower level of the walls for the purpose of reducing internal water pressure.

5.3 Collapsed and demolished walls

To re-establish their original structures, all collapsed and demolished walls were reconstructed using thousands of salvaged red clay bricks from abandoned old terrace houses in Georgetown built between 1892 and 1928 as well as salvaged red clay bricks from the Fort Cornwallis itself. Reconstruction was carefully done by laying down the salvaged bricks according to the original brickworks. Prior to this, the salvaged red clay bricks from the abandon terrace houses had been tested for their compressive strength. Results had shown that all of them had a high level of compressive strength ranging from 24.0 N/mm^2 to 47.8 N/mm^2, which compatible to the compressive strength of the existing red clay bricks found at the Fort Cornwallis.

6 Conclusions

There were a number of building and structural defects identified in the restoration project of the Fort Cornwallis including major and fine cracks, leaning walls and collapsed walls as well as demolished walls. Although the Fort suffered several major structural defects, its original form and shape are still maintained. Upon identification of the structural defects, several structural analyses were carried out on the existing building materials and structures in order to identify their components and strength. Such analyses were important for the purposes of structural rectifications. Solutions for the structural defects of the Fort Cornwallis has been discussed which involved proven techniques and methods such as Peter Cox's method, wall jacking and reconstruction, hence the defected structures have been reinstated to their original forms, positions and look.

The works done on the Fort Cornwallis involved restoring and maintaining the existing building materials and structures that have been defected. All restoration works carried out at the Fort Cornwallis involved only on defected structures with minimum disturbance. The proven techniques and methods applied in the projects were in accordance with international guidelines and

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principles of building conservation. Professional inputs and advice from the experts and consultants involved particularly from the structural engineer were equally important as to ensure the structures of the Fort Cornwallis last for as long as it could.

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