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Civil Engineering Aspects of Thailand's Historical Park Monuments

Sarawut Sapmakmee[1], **Phakin Kwannak**[1*], **Methasit Khongin**[1*], **Cheng Long Liang**[1], **and Gui Gu Ye**[1]

[1]*Faculty of Engineering and Architecture, Rajamangala University of Technology Tawan-ok, Uthenthawai Campus, Bangkok, THAILAND..*

Corresponding Author (Email: Phakin @ gmail.com, Methasit @ gmail.com).

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Abstract

This review highlights the important part that civil engineering plays in keeping and understanding Thailand's historical park monuments, especially the UNESCO World Heritage Site of Ayutthaya. Ancient Thai builders had skills in materials science, using lime mortar and clay brick masonry. Also, hydraulic engineering was applied for water management systems in Sukhothai. In Ayutthaya encounters three problems. The first is the geotechnical instability from soft alluvial soil. The second is related to the deterioration of old masonry structures. The third involves the high risk of flooding. Thus, modern engineering employs advanced geomatics technologies such as LiDAR (Light Detection and Ranging), together with the 3D point cloud data. The observed data is for creating precise geometric documentation, assessment and preservation. It can also monitor structural changes over time (like tilt and settlement). Further, the data provides accurate data for advanced Finite Element Method (FEM) structural analysis. This ensures informed and sustainable conservation strategies.

Discipline: Civil Engineering & Technology, Conservation and Sustainability Engineering.

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1 Introduction

The important historical parks in Thailand include Ayutthaya, Sukhothai, and Si Satchanalai. These are beautiful and religious UNESCO World Heritage cultural sites. They also show how smart the ancient Siamese (Thai) kingdoms were at engineering. Building these monuments required clever solutions to problems in geotechnical engineering, hydrology, materials science, and structural mechanics.

The Sukhothai Kingdom (13th-15th centuries, highway 440km north of Bangkok) and the Ayutthaya Kingdom (14th-18th centuries, roadway 78km north of Bangkok) were times of great achievement for Thai civilization. Their large historical parks display advanced engineering that helped them build impressive structures in a tough tropical environment. The engineering was mainly motivated by religious (Buddhist) and royal needs, resulting in the creation of huge and strong symbolic structures & buildings.

Figure 1: Ayutthaya Wat Yai-Chaimongkol UNESCO World Heritage Sites

Ayutthaya is located where the Chao Phraya, Lopburi, and Pa Sak Rivers meet, which makes it very vulnerable to flooding. This issue has been made worse by recent changes in the river basin and climate change. The 2011 Thailand flood crisis, the devastating flood really put the monuments to the test, as almost all of Ayutthaya City Island was underwater for several months. This flood had severely impacted the UNESCO World Heritage Site (WHS) and the nearby communities (Kittipongvises et al. 2020).

For direct damage, being submerged for such a long time led to serious damage to the ancient bricks and lime mortar, which weakened the masonry. The quick drying process sped up the crystallization of salts, where soluble salts pushed to the surface by evaporating water crystallize in the pores, leading to the peeling and breaking apart of surface layers and wall paintings.

For mitigation engineering, today's civil engineering has introduced solutions like building artificial reinforced concrete wall barriers and flap gates, especially at the riverside temple Wat

Chaiwatthanaram, which is very prone to flooding. This significant engineering effort is designed to safeguard the ruins from the ongoing threat of high water levels.

Considering geotechnical and foundation concerns, the historical park is located on deep alluvial deposits within the Chao Phraya River basin. This type of soft, compressible soil creates long-term challenges for the stability of the large brick structures (Prangs and Chedis). Issues like waterlogging and changes in the water table lead to uneven settling and make the structures more susceptible to movement.

2 Literature Review

Wethyavivorn et al. (2000) explored the historic monuments of Thailand by using finite element models at both the micro-substructure and macro overall structure levels. They focused on how time affects the properties of bricks and the dynamic characteristics of the structure. Also, they looked into how fiber-reinforced cement paste impacts the materials. It was discovered that the elastic properties of masonry can be assessed through substructure modeling techniques. The results from the static stress analysis highlighted important stress components. Over time, the strength of the bricks was found to be stable. Evaluating the dynamic characteristics showed particular mode shape pattern. The addition of fiber-reinforced cement paste to the ancient bricks has enhanced both the strength and energy absorption capabilities of the masonry.

Kuchitsu et al. (2000) studied how salt weathering affects brick monuments in Ayutthaya, Thailand. This was to understand and promote better conservation of built heritage that was suffering from salt weathering. A comparison was made between the severely damaged and well-preserved sections of the monuments to propose methods for minimizing current salt weathering.

Khanjanusthiti (1998) gave a long discussion on conservation of historic monuments in Thailand. Krairiksh (2012) discussed a succinct history of heritage protection in Thailand, as the following. From the mid seventh century, personal devotion was the main reason for conservation. Starting in the mid-nineteenth century, as the government started safeguarding cultural heritage, the focus of conservation shifted from religious devotion to national pride. In the 1960s, development was viewed as a danger to conservation efforts. However, two decades later, the government used conservation as a way to boost economic growth through tourism. Therefore, the evolution of heritage protection reflects the changes in the Thai nation as it transitioned from a traditional Buddhist kingdom to a modern materialistic state.

Wethyavivorn (2016) provided a clearer understanding of the engineering behavior of historic masonry monuments at the Ayutthaya UNESCO World Heritage site. They investigated two main styles of Thai historic masonry monuments: bell-shaped and corn-shaped. First, these structures were analyzed under their own weight using homogenized material properties. Next, frequency analyses were conducted to determine their vibration properties and dynamic response ranges. The in situ ambient frequencies of the two monuments were measured and compared to the analytical frequencies. It was discovered that while the principal compressive stresses for both monument styles were within safe limits, the safety factor against crushing around the entrances of the corn-shaped monument was notably low. Unexpected tensile stress fields were found around the upper middle sections of both styles, which may have contributed to the cracks that are often observed. More consistent dynamic characteristics, like frequency, were identified when the underlying clayey layers were included in the model. With critical stress zones pinpointed, future strengthening programs for these monuments can be designed with greater precision. This could help prevent tension cracks and subsequent damage. The proposed soil-structure interaction model will ensure that no dangerous failure modes, such as torsion, are overlooked.

Chaiyasarn (2018) applied Convolutional Neural Network (CNN) and Support Vector Machines (SVM) for crack detection in historical structures. From a dataset containing images of cracks from masonry structure, the result reached 74% in the testing stage.

Lertcharnrit (2017) discussed that the management of archaeological heritage in Thailand requires further development to address ongoing issues, many of which are similar to those seen in other parts of the world. Destructive activities like changing land for farming, constructing roads & dam, and developing real estate, cause considerable harm.

Siedel et al. (2019) studied historic renders and their weathering at Wat Mahathat, Ayutthaya. They discovered that two distinct kinds of mortars were used. The original mortars, dating back to before 1767, are lime mortars, while hydraulic mortars were clearly employed for the restoration and stabilization of the ruins in the 20th century.

Mahasuwanchai (2020) and Wonganan et al. (2021) studied the physical and engineering characteristics of ancient materials and substitution materials used in the preservation of Thai historical masonry structures, as masonry materials are essential for building historical structures in Thailand. In the lab, they assessed the physical and engineering properties of these masonry materials, including chemical composition, mineralogical composition, density, porosity, absorption, water vapor transmission, compressive strength, and modulus of elasticity. Fly ash was utilized as a pozzolanic material to partially replace slaked lime in order to restore the historical mortar. The binder to sand ratio was maintained at 1:3 by weight. Slaked lime was replaced with fly ash ranging 10-30% by weight of the binder. The engineering properties of the substitution mortars were also analyzed and compared to the ancient masonry materials. A masonry prism was constructed to test the compressive strength and modulus of elasticity of the masonry structures. Using fly ash to partially replace slaked lime helped reduce the setting time and enhance the compressive strength of the historical repair mortar. The empirical model developed from this research could be applied to predict the compressive strength of the masonry prisms in Thailand's historical structures.

3 Results

3.1 Geotechnical and Foundation Engineering: Masonry Structure on Soft Ground

One of the biggest challenges was the soft, alluvial soil found in central Thailand, which could settle and flood during certain seasons. The involved problem is that heavy building, tall brick prangs (temple spires) and chedis (stupas) on soft wet ground could lead to differential/uneven settlement and structural problems. During the current days, it may need to consider earthquake & traffic-induced vibration effects (Poovarodom 2025; Lin 2025). There are some recommended solutions to this problem.

3.1.1 Deep Pile Foundations

Archaeological findings, especially in Ayutthaya, show that wooden piles were driven deep into the ground to reach a more stable layer. These piles, often made from strong woods like teak or takhian, created a solid base that spread the heavy weight of the buildings over a larger area and stopped them from sinking.

3.1.2 Raft Foundations and Artificial Mounds

For bigger complexes, engineers would build artificial mounds by compacting layers of earth and laterite. This raised the construction above the flood zone and gave a more stable foundation. In some cases, a type of raft foundation—a wide, thick base made of laterite blocks—was used to help the structure "float" on the soft soil.

3.1.3 Laterite as a Base Material

Laterite stone is a locally sourced, porous, and relatively soft iron-rich rock that hardens when exposed to air after being quarried. It was widely used for substructures, foundations, and core fill. Its application in foundational layers created a stable and well-draining base for the more decorative brickwork above.

3.1.4 Engineering Significance

This shows a practical grasp of soil mechanics and load distribution. The use of piled foundations came before and aligns with principles found in modern geotechnical engineering to address poor soil conditions.

3.2 Materials Science and Mortar Technology

The durability of the structures is directly linked to the advanced materials utilized.

3.2.1 Brick Production and Bonding

Bricks were locally produced from clay, combined with rice husk or sand to lighten them and enhance firing, then fired in kilns. The accuracy in brick size and shape enabled intricate curves in prangs and chedis.

3.2.2 The Mystery of Ancient Mortar

The most impressive civil engineering achievement is the mortar. Unlike today's cement, it was made from organic materials. Analysis has revealed it usually included:

- Slaked Lime: The main binder, created by burning shells or limestone.
- Sand: Used as an aggregate.
- Organic Additives: This is crucial. Research has found additives like palm sugar, fruit pulp, rice husk, and even sticky rice (Oryza sativa). The polysaccharides in these organic substances served as a composite binder, preventing the growth of calcium carbonate crystals and resulting in a mortar that was more flexible, less brittle, and extremely durable. This mixture has endured centuries of tropical weather, proving to be more resilient in some instances than the bricks it binds together.

3.2.3 Engineering Significance

This represents an early form of polymer-modified mortar. The incorporation of organic compounds to enhance the mechanical properties (ductility, compressive strength, and water resistance) of an inorganic binder is a remarkable innovation in materials science.

3.3 Structural Engineering and Architectural Form

The shapes of the monuments are not solely for aesthetic purposes; they exhibit structural intelligence.

3.3.1 The Chedi (Stupa)

The traditional bell-shaped Sukhothai chedi is a structure that primarily relies on compression. Its curved design effectively directs gravitational forces downward in a stable fashion, thereby minimizing tensile stresses—a force that brick and mortar are not well-equipped to manage. The gradual tapering of the structure reduces the mass at the top, which lowers the center of gravity and improves seismic stability.

3.3.2 The Prang (Khmer-inspired spire)

The Ayutthayan prang, exemplified by those at Wat Mahathat or Wat Ratchaburana, presents a more intricate design. It incorporates a central core with a corbelled arch system. Corbelling entails stacking bricks or stones in progressively cantilevered layers until they converge at the apex. Although this technique creates a false arch that produces considerable lateral thrust, the substantial, thick walls of the *prang* were engineered to contain this thrust, ensuring the stability of the structure.

3.3.3 Load-Bearing Walls and Vaults

Structures such as the viharn and ubosot employed extremely thick load-bearing brick walls to support the weight of heavy, multi-tiered roofs (which were likely constructed from wood and tile). The spans were intentionally kept relatively short, reflecting a practical comprehension of the limitations of their materials.

3.3.4 Engineering Significance

The builders possessed an intuitive understanding of and operated within the compressive strength limits of their materials. They crafted shapes that were inherently stable, utilizing mass and geometry to counteract various forces.

3.4 Hydraulic Engineering: The "Hydraulic City"

Perhaps the most ambitious civil engineering endeavor was the management of water resources. Both Sukhothai and Ayutthaya have been referred to as "hydraulic cities."

3.4.1 Moats and Canals (Klongs)

These structures served purposes beyond mere defense. They were integral to a complex water management system utilized for:

3.4.2 Transportation

Facilitating the movement of construction materials (bricks, stone, laterite) via barge.

3.4.3 Drainage and Flood Control

A network of canals was established to regulate water levels during the monsoon season, safeguarding the city and temple foundations.

3.4.4 Water Supply

The system was designed to store freshwater for use during the dry season.

3.4.5 Reservoirs and Barays

Influenced by Khmer architecture, large reservoirs (barays) were built, such as the one encircling Wat Sri Chum in Sukhothai. These reservoirs ensured a dependable water supply for the populace and supported extensive construction projects, particularly in the production of mortar and bricks.

3.4.6 Engineering Significance

This exemplifies large-scale urban civil engineering planning. The manipulation of the hydraulic landscape was essential for the city's survival, economic success, and its capacity to execute significant construction initiatives.

3.5 Surveying & Geomatics Engineering

Preserving Ayutthaya Monuments can utilize LiDAR (Light Detection and Ranging) and Point Cloud Technology. LiDAR along with the 3D Point Cloud data are crucial geomatics technologies for the preservation, documentation, and structural evaluation of the ancient masonry monuments found in the Ayutthaya Historical Park. This technology provides a non-invasive, highly precise, and quick way to capture the intricate shapes of aging structures.

3.5.1 LiDAR and Point Cloud for Documentation and Archiving

The main use of LiDAR is to create an accurate digital twin of the monuments, which is vital for their long-term conservation and reference.

3.5.1.1 High-Quality Geometric Documentation

Terrestrial Laser Scanning (TLS) devices, like the FARO Focus series, are frequently employed to gather high-density point clouds (millions of points) with millimeter-level precision. This data accurately captures the current dimensions, shapes, and sizes of Ayutthaya's structures, such as the prangs and chedis, resulting in an "as-built" 3D model.

3.5.1.2 Digital Preservation (Digital Twin)

The point cloud acts as a lasting digital record of the monuments' condition at a certain time. This digital version is crucial for future generations, especially if there is severe damage from floods or earthquakes, as it maintains the historical geometry and safeguards cultural information.

3.5.1.3 Integrated Acquisition

Given the size and complexity of the site, various LiDAR technologies are often combined. TLS is used for detailed, close-range scanning of facades and flaws. It can use Airborne LiDAR (ALS) or UAV-based LiDAR for mapping large areas and capturing features that are high up or hard to reach.

3.5.2 Structural Changes Detection

LiDAR and 3D point clouds can help us see and keep track of changes in structures, like the tilting and settling of ancient masonry monuments.

3.5.3 Engineering Significance

Maintaining the Ayutthaya UNESCO WHS Monuments can make use of LiDAR and Point Cloud Technology. These are essential geomatics tools for preserving, documenting, and assessing the structure of the ancient masonry monuments. This technology offers a non-invasive, highly accurate, and fast method to capture the detailed shapes of aging buildings.

4 Case Studies in Engineering

1. Wat Mahathat, Ayutthaya: The central prang of this temple is famous for its collapse. While many believe this was due to the Burmese invasion, it was probably because the foundation failed on the soft soil, which poses a risk for such a tall and heavy structure. The ruins allow us to examine the internal core and the construction methods used.

2. Wat Sri Chum, Sukhothai: This monument is well-known for its huge mondop (a square building) that contains a giant seated Buddha. The impressive engineering here is the corbelled vault ceiling, which covers a large area without relying on a true arch, showcasing advanced weight distribution to form a closed sanctuary.

3. Wat Chang Lom, Si Satchanalai: This chedi, surrounded by elephants, highlights the use of a large, solid laterite core as a stable foundation and structural core, onto which decorative stucco and brick elements were added.

5 Discussion

Thailand's historical parks serve as open-air textbooks showcasing ancient civil engineering. The builders were skilled engineers who created solutions tailored to the tough environmental and logistical challenges they faced. Their legacy lies not only in the spiritual and artistic magnificence of the monuments but also in the evidence of their sophisticated understanding of foundation design on soft soil, the chemistry behind durable composite materials, the principles of compressive structures, and large-scale water management. Their achievements still guide modern conservation efforts and remain a lasting tribute to human creativity.

The historical park monuments in Thailand, especially in Sukhothai and Ayutthaya, provide a great area for civil engineers to explore. The builders from ancient times showed incredible engineering skills, and today, civil engineering is essential for preserving, assessing the structure, and conserving these sites.

6 Conclusion

The conservation of Thailand's historical parks, especially the impressive ruins of Ayutthaya, is essentially a complicated civil engineering project that connects ancient creativity with modern technology. In term of ancient engineering legacy, these structures are proof of the advanced civil and hydraulic engineering skills in Southeast Asia. Studying the old masonry materials and water management systems is vital for creating effective and sustainable repair methods.

Regarding Ayutthaya's main engineering issues, the major threats that need civil engineering solutions include geotechnical risks (because of the soft, compressible soil near the river), material deterioration (made worse by weathering and the natural fragility of ancient lime-based mortar), and severe flood damage. Current projects, such as the protective walls and barriers at Wat Chaiwatthanaram, showcase the large-scale civil works needed for risk reduction.

Seeing the importance of LiDAR and Point Clouds, LiDAR and 3D point cloud technology have evolved from mere documentation tools to crucial engineering resources for preservation. They offer the most precise geometric data for tracking tiny changes over time, conducting accurate structural health evaluations (including seismic vulnerability assessments), and building digital archives. The capability to monitor slight shifts like the tilting of a prang or chedis enables engineers to act early, changing preservation from a reactive approach to a proactive and preventive science.

Civil engineering knowledge can help for effective preservation. This requires the ongoing combination of historical material science, advanced structural analysis, and accurate digital monitoring to safeguard these priceless cultural heritage sites from the unavoidable forces of nature and time.

7 Availability of Data and Materials

All information is included in this article.

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Sarawut Sapmakmee is a doctoral student at Faculty of Engineering and Architecture, Rajamangala University of Technology Tawan-ok, Uthenthawai Campus, Bangkok, Thailand. His research is related to Applied Civil Engineering Technology to solve problems of the country.

Phakin Kwannak is a doctoral student at Faculty of Engineering and Architecture, Rajamangala University of Technology Tawan-ok, Uthenthawai Campus, Bangkok, Thailand. His research is related to Applied Civil Engineering Technology to solve problems of the country.

Methasit Khongin is a doctoral student at Faculty of Engineering and Architecture, Rajamangala University of Technology Tawan-ok, Uthenthawai Campus, Bangkok, Thailand. His research is related to Applied Civil Engineering Technology to solve problems of the country.

Liang Cheng Long is a doctoral student at Faculty of Engineering and Architecture, Rajamangala University of Technology Tawan-ok, Uthenthawai Campus, Bangkok, Thailand. His research is related to Applied Civil Engineering Technology to solve problems of the country.

Ye Gui Gu is a doctoral student at Faculty of Engineering and Architecture, Rajamangala University of Technology Tawan-ok, Uthenthawai Campus, Bangkok, Thailand. His research is related to Applied Civil Engineering Technology to solve problems of the country..