Design aspects of hat type steel sheet pile for Pa Sak River Improvement Project in Thailand

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ABSTRACT

The Pa Sak River Improvement Project is implemented with the aim of enhancing water transport efficiency from the Pa Sak River to the Chao Phraya River and onwards to the sea. This paper focuses on Phase 2 Section 1 of the Project, which mainly consists of construction of a 1855m riverbank protection wall along the Pa Sak River at Ayutthaya province. Double hat type sheet pile wall (45H and 25H) was introduced with depth range from 15 to 21m forming a double wall configuration restraint by capping beam and slab. To review on the design aspects, analysis sections of double hat type sheet pile wall were selected and carried out. Analyses were conducted by using finite element program, Plaxis 2D, to examine in terms of forces, deformations, stability, and factor of safety. Forces were verified to ensure the adequate hat type sheet pile wall structural properties. The results indicate that the double hat type sheet pile wall performs well, offering an improved design solution. As a result, the pioneering use of the double hat type sheet pile wall installed using the SILENT PILER™ with water jetting method sets a future trend for revetment wall construction in Thailand, providing a more efficient and effective approaches.

Key words: *Hat Type Steel Sheet Pile, Pa Sak River, SILENT PILER*

1. Outline of the project

1.1. Project background

The Pa Sak River is an important river that transport goods via waterways within the country since the river flows through the origin and destination areas of goods in the construction industries and various agricultural productions. It is connected to the Chao Phraya River, the main river linked to Bangkok and gulf of Thailand.

At present, water traffic is very dense and congested. In addition, the physicality of the river itself is an obstacle to navigation, such as problems with width, depth, and winding of the river as well as shallowness of the channel in the dry season. This makes it difficult for ship navigation, which affects the overall picture of transporting goods along the country's rivers.

1.2. Objectives of the project

The project is to construct a riverbank protection wall to prevent erosion on the Pa Sak River and increase the potential for transporting goods via the domestic river and to support the 11th National Economic and Social Development Policy and Plan in developing the mode of water and rail transportation, which is energy-saving transportation and logistics cost reduction.

The Marine Department has tried to solve the problem of the shallowness of the river by dredging out sediment to increase the depth of the river. However, people with houses and buildings located along the riverbank were concerned about the stability of riverbank, which may impact and damage their properties. To facilitate the development of navigation channels through river dredging, it is essential to conduct this activity

simultaneously with the construction of riverbank protection dams. This approach aims to mitigate riverbank erosion and enhance stability before proceeding with dredging and subsequent channel development.

This paper focuses on Phase 2 Section 1 of the Project, which mainly consists of construction of a 1855m riverbank protection wall along the Pa Sak River, dredging of river channels, construction of walkway, guardrails and other related works at Ayutthaya province as shown in Figure 1.

Fig. 1 Map of Pa Sak River with Central Part of Thailand

2. Site condition, Structural type, and piling method

2.1. Site condition

The Project located in the city area of Ayutthaya province, a historical city of Thailand. It is surrounded by historical temples, dense housing area, agricultural land, which lead to the requirement on noise and vibration reduction during construction. Furthermore, the limited working space also needs to be considered for this project.

As shown in Figure 2, construction of riverbank protection dam for Phase 2 Section 1 was divided into 6 zones with different configurations.

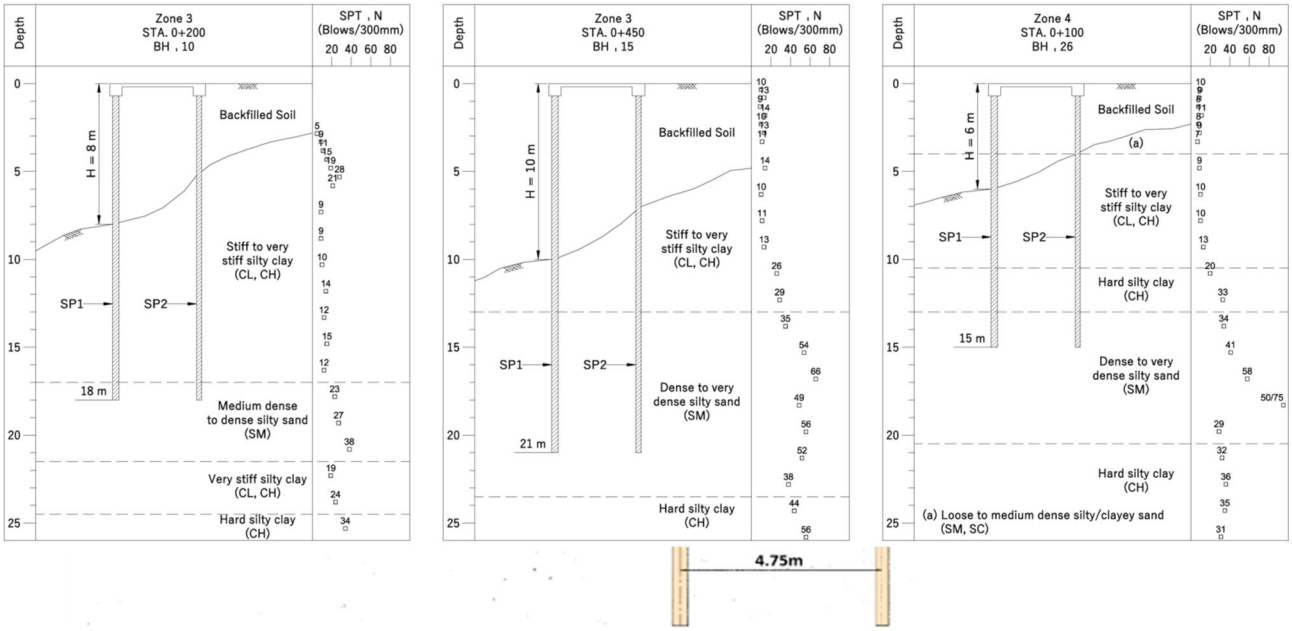
2.2. Ground condition

The project area is in the lower central plains area, so called the Chao Phraya Basin. It is a basin that slopes from north to south with a quaternary period sediment that accumulated in this basin. The Pleistocene deposits of the Lower Central Plain represent a complex interplay of alluvial, fluvial, and deltaic environments of the Chao Phraya River and its tributaries.

The term “Chao Phraya delta” is used to define the landform where the Chao Phraya River interacted with marine processes as the sea level changed during the Holocene transgression. This complex sea level history has caused delta deposits, consisting of soft marine clay, sequence of sand and stiff clay deposited.

In this Project, 36 nos. of boreholes including field and laboratory tests were carried out along the riverbank

Fig. 2 Overview of Phase 2 Section 1 of Pa Sak River Improvement Project



protection wall. Information from these ground results are incorporated to supplement the design and to minimize the risk of unexpected ground conditions along the riverbank protection wall.

Disturbed samples from both the cohesive and cohesionless strata are generally obtained from split spoon sampler of the Standard Penetration Test that was performed generally at 1.0-1.5m intervals. The soil found in the project area are generally stiff ground consist of stiff to very stiff clay and dense sand with SPT-N value increasing with depth as shown in Figure 3.

2.3. Structural type and piling method

In Thailand, the soldier pile retaining wall is a conventional type of retaining wall used in a numerous project. It consists of prestressed concrete piles (I-shape) installed at regular intervals along the excavation perimeter with inserted prestressed concrete panels in between as shown in Figure 4. The soldier pile retaining wall system is often chosen for its versatility and relatively straightforward construction process. However, it was found that some of the retaining walls had significantly deformed and even collapsed. The possible causes of failure are due to the cyclic of water during the operational life (Soralump, 2019). The loss of stability caused damage to both the retaining wall itself and adjacent structures.

Furthermore, due to some constraints on difficulty of pile driving in stiff ground, environmental noise and vibration impact, therefore this conventional type may not be suitable for Pa Sak River Project. In addition, the requirement from Marine Department also stated that "use a sheet pile installation technique that does not increase risk factors for the stability of the current riverbank slope by using Press-in technology or the hi-frequency vibro method with a revolution of not less than 2,200 rpm". Hence, Press-in technology was introduced in this project.

The project, specifically Part 1 of Phase 2, marks a pioneering initiative in Thailand by employing hat type steel sheet piles constructed by Press-in method with water-jetting mode. Hat type steel sheet piles were employed for riverbank protection wall purposes and configured to form a double wall. This type of structure is formed similar to a cofferdam which is more stable compared to the conventional type of retaining wall.

Fig. 4 Conventional type of riverbank protection wall

With the SPT N value of approximately 10-15 at depth up to 10m and gradually increase with the maximum value of more than 50 for this project, the Press-in with

water jetting method was adopted by utilizing GIKEN's SILENT PILER F301-900 model. Water jetting press-in technology efficiently reduces penetration resistance force and prevents pile damage.

In this project, 45H and 25H hat type sheet piles were employed along the riverside (SP1) and landside (SP2), respectively. A concrete capping beam with tie beam and slab was then carried out to form a double wall system and served as a pedestrian walkway, as depicted in Figure 5. To benefit the community, sidewalks and stairs were provided to enhance the resident's living environment. With a total of 1855m riverbank protection wall along the Pa Sak River with a variation in ground elevation and water channels profile, it is separated into 3 categories different in depth as summarized in Table 1.

wall, length of sheet pile, and geological ground condition as summarize below:

- Zone 3 STA0+200 – double hat type sheet pile wall with retaining height of 8m and sheet pile length of 18m.
- Zone 3 STA0+450 – double hat type sheet pile wall with retaining height of 10m and sheet pile length of 21m.
- Zone 4 STA0+100 – double hat type sheet pile wall with retaining height of 6m and sheet pile length of 15m.

Analyses were conducted by using finite element program, Plaxis 2D, to examine in terms of forces, deformations, stability, and factor of safety.

Fig. 5 Cross section of Pa Sak riverbank protection wall by using hat type steel sheet pile

Table 1. Details of Sheet Pile Wall in This Project

Height of Wall	Double Sheet Pile Type		Length of Sheet Pile
m	Front	Back	m
6	SP1 – 45H	SP2 – 25H	15
8	SP1 – 45H	SP2 – 25H	18
10	SP1 – 45H	SP2 – 25H	21

Hat type steel sheet pile was developed as a new generation sheet pile with improved drivability, higher structural reliability, and more economical merit compared with traditional U-type sheet piles (Nippon Steel, 2008). Subsequently, 45H and 50H hat type was added and released to the market in 2014 (Nippon Steel and Sumitomo Metal, 2016).

Moreover, hat type steel sheet pile are widely used for river revetment protection wall worldwide especially in Japan. For instance, river revetment wall in Fukuoka City, Fukuoka, Japan was constructed using hat-shaped steel sheet piles installed by Press-in method with water jetting (GIKEN, 2023).

3. Design aspects of hat type steel sheet pile

3.1. Overview

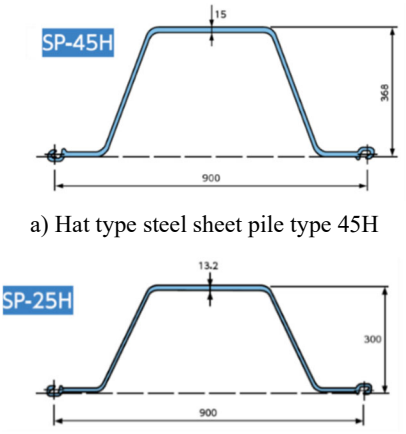
To review the design, analysis sections of double hat type sheet pile wall were chosen and carried out. Three selected sections were selected with different in height of

3.2. Sheet pile properties

As indicated in Table 1 above, hat type sheet pile along the riverside (front sheet pile – SP1) is type 45H, while along the landside (back sheet pile – SP2) is type 25H. Hat type steel sheet piles are a specific type of sheet pile used in construction and civil engineering projects, particularly in applications involving retaining walls, cofferdams, and other types of earth retention systems.

Key features and characteristics of Hat type steel sheet piles are outline below:

- Profile shape: Hat type steel sheet piles have a distinctive shape resembling the letter "HAT", which gives them their name.
- Strength and durability: Hat type steel sheet piles are designed to provide high strength and durability, making them suitable for use in challenging soil and water conditions.
- Interlocking design: Similar to other types of sheet piles, hat type piles are designed to interlock with each other to form continuous walls or barriers.
- Variety of sizes and lengths: Hat type steel sheet piles are available in various sizes and lengths to accommodate different project requirements.
- Installation methods: Hat type steel sheet piles can be installed using various methods, including conventional driving, or press-in technology.



a) Hat type steel sheet pile type 45H

b) Hat type steel sheet pile type 25H

Fig. 6 Cross section of hat type steel sheet pile (Nippon Steel, 2019)

Overall, hat type steel sheet piles offer a versatile solution for retaining walls and other earth retention structures, combining strength, durability, and ease of installation. Cross sections of hat type steel sheet pile type 45H and 25H are illustrated in Figure 6. Hat type sheet pile properties are indicated in Table 2.

Table 2. Requirements of Steel Sheet Pile Properties

Sectional Properties		SP1 (Front) 45H	SP2 (Back) 25H
Per 1m wall	Unit		
Sectional Area	cm^2/m	160	125
Moment of Inertia	cm^4/m	45,000	24,000
Section Modulus	cm^3/m	2,400	1,600

3.3. Interlock integrity

Among its advantages, the hat type sheet pile offers a benefit in terms of design. It allows for obviating the need for a "reduction factor" consideration due to the interlocking position not being situated on the center line (neutral axis position) of the sheet pile wall. Interlock of the hat type sheet pile does not slip together when subject to earth/water pressure as shown in Figure 7. Therefore, for a wall using Hat type steel sheet piles, the reduction of sectional properties is not required.

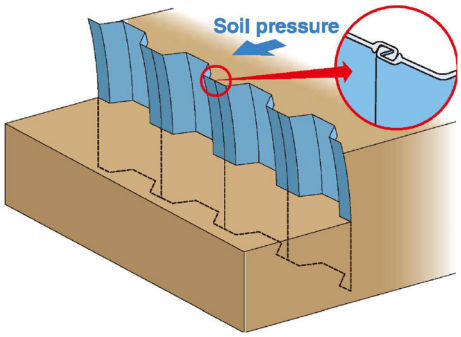


Fig. 7 Non-slippage interlock of hat type steel sheet pile (Nippon Steel, 2019)

When compared to a wall using U-type steel sheet piles with the interlocking position located at the center (neutral axis position), the shear force would not transmit sufficiently between the adjacent due to the interlocks slip from each other. Hence, the moment of inertia and section modulus of the wall of the U-type sheet piles need to be reduced. This can be referred to as "lack of interlock integrity".

3.4. Plaxis analysis

The geotechnical engineering finite element program, Plaxis 2D, was used to analyze such soil-structure interaction including construction sequences and the effects of soil and water lateral loads on the internal forces and deformation of the sheet piles.

Soils are modelled as elastic-perfectly plastic materials following the Mohr-Coulomb failure criterion. Hat type sheet pile is modelled as linear-elastic plate elements with material properties defined by flexural rigidity EI and axial normal stiffness EA. Concrete tie beam is modelled as plate elements with flexural rigidity and axial normal stiffness to connect between front and back sheet pile before backfilling. Interface elements between sheet pile walls and soils was applied in the model. Properties of soils and sheet pile walls are summarized in Table 3 and Table 4, respectively.

Model was set with a dimension of 60m in width and 35m in height to minimize the impact of boundary effects. The initial lateral soil stress regime prior to sheet pile wall installation is modelled using at rest (Ko) earth pressure coefficients. Water level is set at the lowest level during construction as specified in the specification. During subsequent excavation stages as specified in the drawing, ground pressure redistribution occurs in relation to the

wall deformation and stiffness of the wall, soil and strutting system.

Table 3. Soils Properties in Numerical Model

Soil Layer	Drainage Type	Unit weight, γ	Undrained shear strength, S_u	Cohesion, c'	Friction angle, φ'	Elastic Modulus, E	Coefficient of earth pressure at rest, K_0
		kN/m^3	kN/m^2	kN/m^2	°	kN/m^2	-
(A) Top soil	Undrained	18.0	30	-	-	6250	0.60
(B) Stiff clay	Undrained	20.5	75	-	-	31250	0.69
(C) Stiff clay	Undrained	20.5	45	-	-	18750	0.69
(D) Very stiff clay	Undrained	20.5	80	-	-	33300	0.69
(E) Medium dense to dense sand	Drained	21.0	-	0	35	56000	0.43
(F) Very stiff clay	Undrained	21.0	130	-	-	54000	0.64
(G) Hard clay	Undrained	21.0	160	-	-	66600	0.64
(H) Fill material	Undrained	18.0	30	-	-	6250	0.60

Table 4. Steel Sheet Pile Properties in Numerical Model

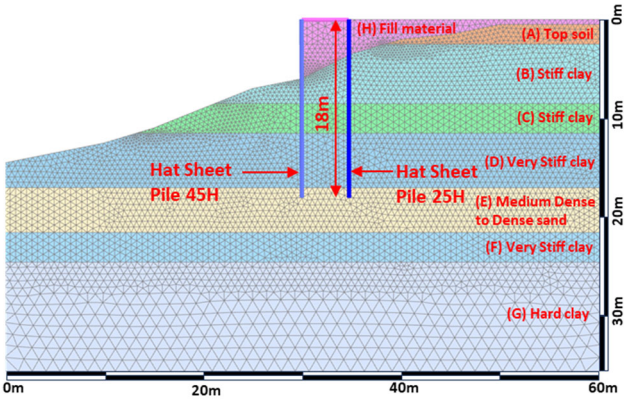
Input Sectional Properties in Numerical Model		Hat type steel sheet pile 45H	Hat type steel sheet pile 25H
Per 1m wall	Unit		
Axial Stiffness, EA	kN/m	4.16 x 10^6	3.21 x 10^6
Flexural Stiffness, EI	kNm^2/m	90.0 x 10^3	48.8 x 10^3

3.5. Analysis results

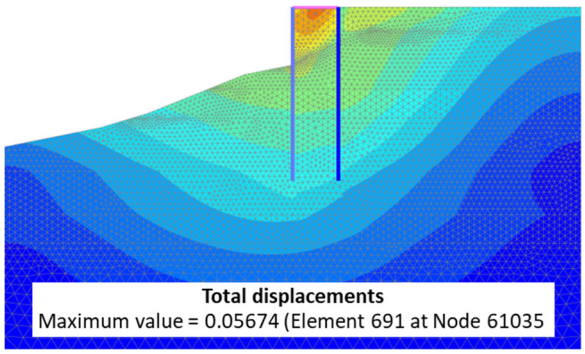
Once the model is set up, the software calculated the stresses, strains, displacements, and other relevant parameters within soils and structures. The results are interpreted and assessed stability and performance of the structures. Results of Zone 3 STA0+200 are illustrated as shown in Figure 8 in terms of mesh generation, deformed mesh results, and factor of safety. Summary of analysis results of three selected sections including sheet pile deflections, bending moments, and factor of safety are tabulated in Table 5 below.

3.5.1. Forces

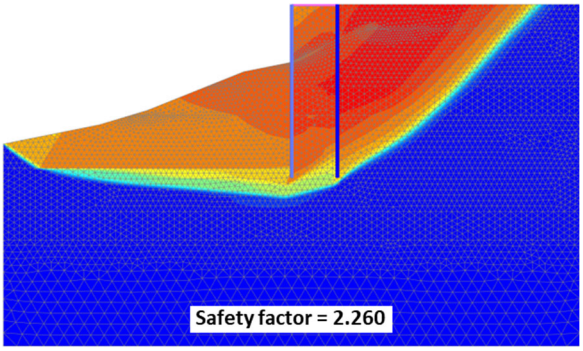
By analyzing complex force interactions, forces generated in hat type sheet pile wall are summarized in Table 5. A check was made to reaffirm and ensure hat sheet pile with sufficient strength, stability, and durability. Based on a section modulus of hat sheet pile with the minimum yield strength of 295 MPa, it can be able to withstand bending moment up to 250 kNm and 166 kNm for hat sheet pile 45H and 25H, respectively.



a) Mesh generation



b) Deformed mesh



c) Safety factor calculation

Fig. 8 Plaxis results for selected section Zone 3 STA0+200

3.5.2. Deformations

The deflection of a hat type sheet pile wall deforms or moves under the applied loads and soil pressures. As depicted in Table 5, SP1 tends to deflect more with a range between 45-60mm, while SP2 tends to move around 25-30mm. Generally, deformations of less than 100mm are acceptable.

3.5.3. Factor of safety

Global safety factors can be computed in Plaxis 2D. The shear strength parameters as well as the tensile strength are successively reduced until failure of the structure occurs to obtain factor of safety. For global stability, a minimum safety factor of 1.5 is generally required. The results indicated the factor of safety more than 2.2, which are satisfactory.

Based on the analysis results, it can be seen that double hat type sheet pile wall performed well providing the alternative solution in Thailand's future market. A design aspects of double hat type steel sheet pile wall has been reviewed and verified to ensure that the double hat type steel sheet pile wall meets the required performance and safety standards.

Table 5. Summary of Analysis Results

Selection Sections	Deflections (mm)		Bending Moments (kNm/m)		Factor of Safety
	SP1	SP2	SP1	SP2	
Zone 3 STA0+200	60.1	29.6	106.7	20.4	2.26
Zone 3 STA0+450	57.7	23.9	70.6	16.2	2.62
Zone 4 STA0+100	45.3	26.9	47.2	13.8	2.64

4. Construction overview

The engagement of Press-in method by utilizing GIKEN's SILENT PILER F301-900 model together with water jetting method was successfully performed. The Press-in method was chosen due to its eco-friendliness. The Press-in machine generates minimal noise and produces nearly no vibrations. Refer to the newsletter about this project (Kitamura, 2023), it can also be applied adjacent to residential areas as shown in Figure 9.

Figure 10 shows the aerial view of Zone 3 double hat type sheet pile wall with retaining height of 10m and sheet pile length of 21m. Notably, the structure is nearing completion, featuring both a capping beam and soil backfill.

Fig. 9 Installation of hat type sheet pile using SILENT PILER adjacent to buildings

Fig. 10 Aerial view of nearly completed structures

5. Concluding remarks

The design characteristics of the double hat type

sheet pile wall for the Pa Sak River improvement project have undergone thorough review and implementation. Analyses were carried out utilizing the finite element program, Plaxis, to assess factors such as forces, deformations, stability, and the factor of safety. The findings demonstrate that the double hat type sheet pile wall performs admirably, presenting an enhanced design solution.

In conclusion, the innovative utilization of the double hat type sheet pile wall, installed via Press-in technology utilizing SILENT PILER with water jetting method, establishes a forthcoming trend in river protection wall construction in Thailand, offering a more streamlined and efficient approach.

6. Acknowledgements

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