The first application of double hat-type sheet pile revetment installed by press-in method in Thailand: Pasak River Bank Protection Project

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ABSTRACT

The Pasak River is one of the major rivers in Thailand. It starts in Loei province in the upper northeast and flows into the Chao Praya River at Phra Nakhon Si Ayutthaya province. The 51.22 km river distance from the Chao Praya River is studied as one of the national ship routes for transportation networks. There are three main objectives to construct the Pasak River bank protection wall. The first reason is that there are areas where more water depth is required during the low water level period for ship navigation passage. Second, the river width needs to be widened for ship navigation passage. Third, there is a high risk of bank erosion and slope stability affecting the people's houses. During the design process, the geographical features and limitations of the existing river bank were found. The paper includes the soil and geographic characteristics of the Pasak River and the design of the double hat-type sheet pile wall installed by the Press-in Method, which is the first application in Thailand. Using the Press-in Method during the construction would not disturb the existing ground soil, which would not cause to a decrease in soil strength of the river bank and would reduce environmental effects.

Key words: *Bank protection, Ship navigation, Bank erosion, Double hat-type sheet pile wall*

1. Outline of the project

1.1. Place

The Pasak River originates in Loei Province, upper northeastern in Thailand, and the length is 513 km. The river basin area is around 14,520 sq km, long and narrow, and passes through Phetchabun, Lopburi and Saraburi provinces, and runs into the Chao Praya River at Phra Nakhon Si Ayutthaya province. It is considered as part of the Chao Phraya Plain as shown in **Figure 1**.

1.2. Background and objectives of the project

The economic growth of a country depends on many factors, and the development of freight transport is an important one. In Thailand, land transportation, such as trucks and trains, is widely used, while water and air transportation are less common. Water or ship transportation even has lower costs than other modes, but it takes a longer time and it is suitable for products with a long shelf life. The ship transportation is an option for businesses that are located not far from shipping routes. Therefore, the shipping route has been developed on the potential river.

The water transportation in rivers and canals has been used since the past. Currently, the quantity and weight of cargo are increasing and the sizes of ships have increased, which requires sufficient depth and width of the rivers. The Chao Phraya River is the main river and it has been used for sea freight. On the other hand, the other rivers have limitations of hydrology and topography including the number of businesses. However, the Pasak River has high potential as a route for the existing businesses for transporting raw material and finished products and can connect to the shipping routes of the Chao Phraya River which is the main route and can run into the sea. There are some businesses along the project route such as the animal feed production plants and the cement manufacturing plants, etc. They carry the raw materials, oil or coal as a fuel to be used in the production process, and transport products to sell or keep in warehouses in Bangkok and also the other provinces, or waiting for export.

Figure 1. The rivers in Chao Praya Plain (WIKIPEDIA, 2024.)

The study focuses on a 51.22 km section of the Pasak River. The lower part of the route is on the central river plain of the Chao Phraya River, whose river deposits are made up of clay and silty soil with sand layers. The Pasak River is meandering, with some narrow sections and issues with slope stability of the riverbank. There are many buildings along the riverside. The feasibility of the project in terms of economics, engineering, and environment has been studied. During the design stage, the surveys and designs for river bank protection construction were conducted. The necessity for construction can be summarized into the following three main reasons:

1) The depths of the river in some areas are not sufficient for navigation during the dry season when the water level in the river is low. Therefore, dredging is required to make the river bed deeper enough for navigation. However, digging the soil deeper will affect the stability of the riverbank slope.

2) The width of the river needs to be widened so that ships can navigate and pass each other safely. This will result in steeper riverbank slopes, which will affect the stability of the riverbank.

3) There is erosion and collapse of the riverbank, which affects people's houses.

2. Geography and limitation of the existing river bank area properties

The study area of the Pasak River is between the floodgates of the Rama VI Dam in Tha Ruea district, which runs into the Chao Phraya River at Wat Phanang Choeng. There are some meandering channels, soil erosions and high fluctuations in river water levels. As the river moves away from its mouth, the bank will be higher. Along the project area, there are many residential areas, factories, warehouses, temples including local official buildings, which are densely located in some areas and scattered along the river. The river boundaries of some areas are narrow. Some private individuals occupy land adjacent to the river and buildings extending beyond the river boundary. In some places, the riverbeds are shallow, which need to be dredged to increase the height of the embankment. The various factors affect the design and setting of the characteristics of the embankment protection structure to ensure it is appropriate and has minimal impact on the surrounding areas.

3. Ground condition

3.1. Soil investigation results

The results of soil survey drilling from 100 boreholes, taken every 0.5 km on the left and right sides of the river, have found variations of soft and hard clay layers alternating with loose to very dense sand layers and different layer thicknesses. An example of the soil profiles between km 0 – 8 is shown in **Figure 2**.

3.1.1 Groundwater table level

Sixteen observation wells were installed to measure groundwater levels. It was found that the groundwater levels ranged from 0.5 m to 1.0 m below the existing ground level in the lower Chao Phraya River Basin, and from 1.5 m to 2.0 m or deeper from km 30 to the end of the project area, as shown in **Table 1**.

3.1.2 Group of soils

The soil layer characteristics are variable. They are categorized into 15 groups as shown in **Table 2**, with each group corresponding to a different km range, as shown in **Table 3**.

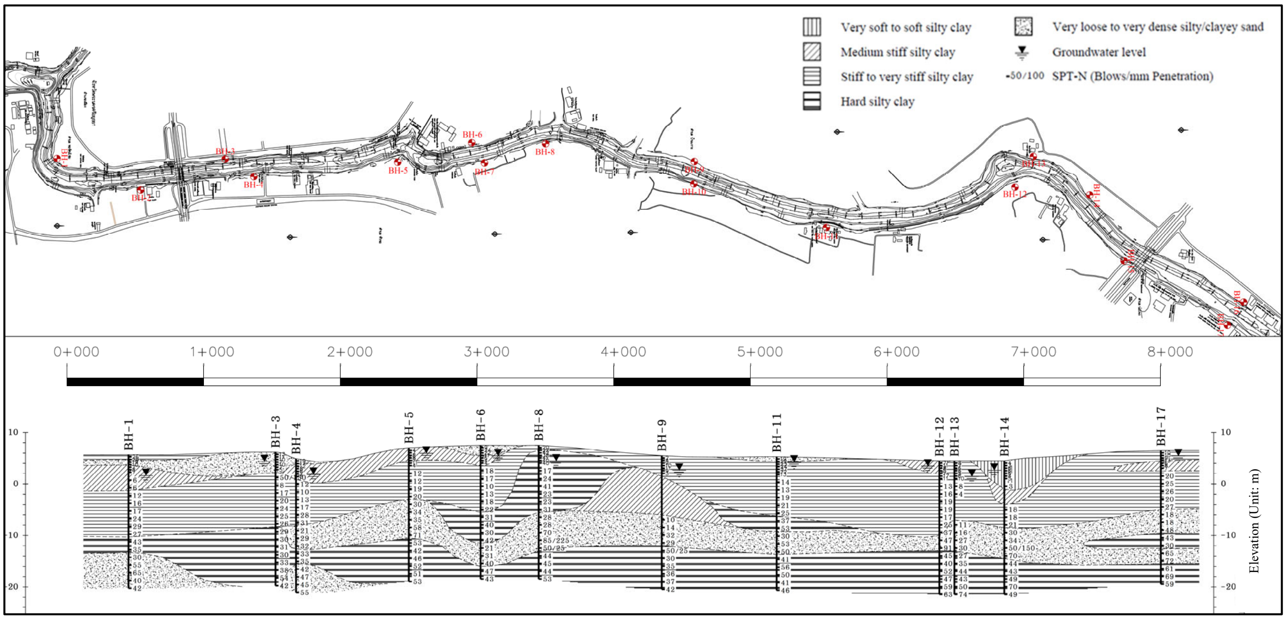

Figure 2. Soil profile of km 0–8

Table 1. Ground water table record

Observation Well (OB)		Ground Water Level Measured Below Ground Surface (m)			
Name	Station, Km	Installation and initial Reading, during 6-12 May 2018	2nd Reading, 4 August 2018	3rd Reading, in Rainy Season	Approx. Depth Change of Ground Water Level
CH1	5+000 R	2.45	2.36	0.09	0.5
CH2	6+500 L	1.35	1.23	0.12	
CH3	9+400 L	2.42	1.94	0.48	
CH4	12+900 L	1.33	0.67	0.66	
CH5	15+600 R	1.7	1.04	0.66	
CH6	21+800 R	2.67	1.63	1.04	1.0
CH7	24+700 L	2.69	1.53	1.16	
CH8	26+950 R	1.95	0.54	1.41	
CH9	30+700 L	3.75	2.77	0.98	
CH10	33+600 L	1.75	Flooding	-	1.5
CH11	36+500 R	2.34	0.32	2.02	2.0
CH12	38+700 R	0.69	Flooding	-	
CH13	42+400 R	3.85	2.15	1.7	
CH14	45+400 R	2.73	Malfunction	-	
CH15	50+000 R	3.85	Malfunction	-	
CH16	51+000 R	3.6	Flooding	-	

Table 2. Group of soils

Soil Group	Layer No.	Soil Type	Depth (Approx), m		Unit Weight	Su	λ	Su,corr	ø	E	ν
			From	To	kN/m^3	kN/m^2		kN/m^2	°	kN/m^2	
Group 1	1	Medium Stiff Clay	0	5.0	18.5	20	0.5	10.0	-	2,500	0.3
	2	Stiff to Very Stiff Clay	5.0	16.0	19.5	80	0.5	40.0	-	10,000	0.3
	3	Dense Sand	16.0	20.0	19.5	-	-	-	36.0	30,000	0.3
Group 2	1	Medium Stiff Clay	0	6.0	18.5	20	0.5	10.0	-	2,500	0.3
	2	Medium Dense Sand	6.0	12.0	18.0	-	-	-	33.0	20,000	0.3
	3	Hard Clay	12.0	15.0	20.0	200	0.4	80.0	-	20,000	0.3
	4	Dense Sand	15.0	18.0	19.0	-	-	-	36.0	30,000	0.3
	5	Hard Clay	18.0	20.0	20.0	200	0.4	80.0	-	20,000	0.3
Group 3	1	Soft Clay	0	5.5	15.0	10	0.5	5.0	-	1,250	0.3
	2	Medium Stiff Clay	5.5	8.5	17.5	20	0.5	10.0	-	2,500	0.3
	3	Stiff to Very Stiff Clay	8.5	13.0	19.5	80	0.4	32.0	-	8,000	0.3
	4	Dense to Very Dense Sand	13.0	19.0	20.0	-	-	-	36.0	30,000	0.3
	5	Hard Clay	19.0	20.0	20.0	200	0.4	80.0	-	20,000	0.3
Group 4	1	Medium Stiff Clay	0	2.5	18.5	20	0.4	8.0	-	2,000	0.3
	2	Stiff to Very Stiff Clay	2.5	7.0	19.5	80	0.4	32.0	-	8,000	0.3
	3	Medium Stiff Clay	7.0	16.0	18.5	25	0.7	17.5	-	4,375	0.3
	4	Hard Clay	16.0	18.0	20.0	200	0.4	80.0	-	20,000	0.3
	5	Dense to Very Dense Sand	18.0	20.0	20.0	-	-	-	36.0	30,000	0.3
Group 5	1	Medium Stiff Clay	0	11.5	18.5	20	0.5	10.0	-	2,500	0.3
	2	Medium Dense Sand	11.5	14.5	18.0	-	-	-	33.0	20,000	0.3
	3	Medium Stiff Clay	14.5	17.5	18.5	20	0.5	10.0	-	2,500	0.3
	4	Medium Dense Sand	17.5	20.5	18.0	-	-	-	33.0	20,000	0.3
	5	Hard Clay	20.5	24.5	20.0	200	0.4	80.0	-	20,000	0.3
Group 6	1	Stiff to Very Stiff Clay	0.0	10.0	19.5	80	0.4	32.0	-	8,000	0.3
	2	Medium Stiff Clay	10.0	12.0	18.5	20	0.5	10.0	-	2,500	0.3
	3	Stiff to Very Stiff Clay	12.0	15.0	19.5	80	0.4	32.0	-	8,000	0.3
	4	Hard Clay	15.0	24.0	20.0	200	0.4	80.0	-	20,000	0.3
Group 7	1	Soft Clay	0	7.0	15.0	10	0.5	5.0	-	1,250	0.3
	2	Medium Stiff Clay	7.0	11.5	17.5	20	0.5	10.0	-	2,500	0.3
	3	Stiff to Very Stiff Clay	11.5	19.0	19.5	80	0.4	32.0	-	8,000	0.3
	4	Hard Clay	19.0	25.0	20.0	200	0.4	80.0	-	20,000	0.3
Group 8	1	Stiff to Very Stiff Clay	0.0	12.0	19.5	80	0.4	32.0	-	8,000	0.3
	2	Medium Dense Sand	12.0	15.0	18.0	-	-	-	33.0	20,000	0.3
	3	Stiff to Very Stiff Clay	15.0	25.0	19.5	80	0.4	32.0	-	8,000	0.3

Soil Group	Layer No.	Soil Type	Depth (Approx), m		Unit Weight	Su	λ	Su,corr	ø	E	ν
			From	To	kN/m^3	kN/m^2		kN/m^2	°	kN/m^2	
Group 9	1	Medium Stiff Clay	0	5.5	18.5	20	0.5	10.0	-	2,500	0.3
	2	Stiff to Very Stiff Clay	5.5	8.5	19.5	80	0.4	32.0	-	8,000	0.3
	3	Medium Dense Sand	8.5	14.5	18.0	-	-	-	33.0	20,000	0.3
	4	Hard Clay	14.5	24.5	20.0	200	0.4	80.0	-	20,000	0.3
Group 10	1	Stiff to Very Stiff Clay	0.0	15.0	19.5	80	0.4	32.0	-	8,000	0.3
	2	Hard Clay	15.0	30.0	20.0	200	0.4	80.0	-	20,000	0.3
Group 11	2	Stiff to Very Stiff Clay	0.0	11.0	19.5	80	0.4	32.0	-	8,000	0.3
	2	Medium Stiff Clay	11.0	11.5	17.5	20	0.5	10.0	-	2,500	0.3
	3	Dense Sand	11.5	14.5	19.0	-	-	-	35.0	30,000	0.3
	4	Hard Clay	14.5	19.5	20.0	200	0.4	80.0	-	20,000	0.3
Group 12	1	Soft Clay	0.0	2.0	16.0	20	0.4	8.0	-	2,000	0.3
	2	Stiff to Very Stiff Clay	2.0	8.0	19.5	80	0.4	32.0	-	8,000	0.3
	3	Soft Clay	8.0	11.0	16.0	20	0.4	8.0	-	2,000	0.3
	4	Medium Dense Sand	11.0	14.0	18.0	-	-	-	33.0	20,000	0.3
	5	Hard Clay	14.0	24.0	20.0	200	0.4	80.0	-	20,000	0.3
Group 13	1	Medium Stiff Clay	0	10.0	18.5	20	0.5	10.0	-	2,500	0.3
	2	Medium Dense Sand	10.0	14.5	18.0	-	-	-	33.0	20,000	0.3
	3	Dense Sand	14.5	26.5	19.0	-	-	-	35.0	30,000	0.3
Group 14	1	Medium Dense Sand	0.0	14.5	18.0	-	-	-	33.0	20,000	0.3
	2	Dense Sand	14.5	26.5	19.0	-	-	-	35.0	30,000	0.3
	3	Hard Clay	26.5	30.0	20.0	200	0.4	80.0	-	20,000	0.3
	4	Dense Sand	30.0	34.5	19.0	-	-	-	35.0	30,000	0.3
	5	Hard Clay	34.5	40.0	20.0	200	0.4	80.0	-	20,000	0.3
Group 15	1	Stiff to Very Stiff Clay	0.0	4.0	19.5	80	0.4	32.0	-	8,000	0.3
	2	Soft Clay	4.0	10.0	16.0	20	0.4	8.0	-	2,000	0.3
	3	Hard Clay	10.0	20.0	20.0	200	0.4	80.0	-	20,000	0.3

Table 3. Soil group along the river (km)

Distance	Soil Group
km 0+000 to 5+500	Group 1
km 5+500 to 7+000	Group 2
km 7+000 to 8+500	Group 3
km 8+500 to 10+250	Group 2
km 10+250 to 12+250	Group 4
km 12+250 to 14+250	Group 5
km 14+250 to 16+500	Group 6
km 16+500 to 17+000	Group 7
km 17+000 to 18+250	Group 8
km 18+250 to 19+000	Group 9
km 19+000 to 21+500	Group 7
km 21+500 to 24+000	Group 6

Distance	Soil Group
km 24+000 to 26+500	Group 10
km 26+500 to 32+000	Group 7
km 32+000 to 34+000	Group 10
km 34+000 to 34+750	Group 3
km 34+750 to 35+500	Group 11
km 35+500 to 36+500	Group 3
km 36+500 to 39+500	Group 12
km 39+500 to 41+000	Group 1
km 41+000 to 42+000	Group 10
km 42+000 to 46+000	Group 13
km 46+000 to 49+000	Group 14
km 49+000 to 53+000	Group 15

3.2. Representative soil layers to be used for the design

The 15 soil groups which have similar characteristics in terms of strength are classified into soil types A, namely A, B, C, D and E. Additionally, these types are further classified into groups based on their relative hardness: S (Strong Characteristics) and W (Weak Characteristics). The classification and the percentage likelihood of each type of being found are shown in **Table 4**. It is observed that group character W is more prevalent than S. The information used for design is summarized in **Table 5**.

4. Type of river bank protection

Before this project as Phase 2, there was the Pasak River bank protection in Phase 1 using soil cement column and sheet piles. For Phase 2 design, three general points were considered as follows:

1) During construction, the original soil of the river bank shall not be disturbed because most of the upper soil layers have low strength.

2) The soil properties used in calculation are grouped and applicable to additional soil test results during construction.

Table 4. Summary of soil type

Soil Type	Soil Group	Approx. Distance, km	Percentage of Distance	Soil Group Type	Percentage of Distance
A	6, 8, 10, 11	12	23%	S (Strong Characteristics, Relatively)	42%
B	4, 9, 12, 15	10	18%		
C	1, 3, 7	19	35%	W (Weak Characteristics, Relatively)	58%
D	2, 5, 13	9	17%		
E	14	3	6%		
Sum		53	100%		100%

Table 5. Soil types as a representative soil character

Character	Soil Type	Representative Soil Group	Distance, From - To, km-km	Soil Description of Depth 25 m Below the Ground Surface
S	A	10	17–42	Stiff to hard clay 10–15 m thick above medium dense to dense sand and hard clay
	B	9	10–51	Soft to medium stiff clay 3–5 m alternating stiff clay and medium dense sand
W	C	3	0–41	Soft to medium stiff clay 6–10 m above stiff clay and medium dense sand
	D	5	5–14, 42–46	Soft to medium stiff clay 6–18 m above medium dense sand
	E	14	46–49	Medium dense sand 15 m above dense sand

3) Environmental impacts during construction, such as vibration, noise, and smoke, should be minimized.

During the design stage, various types of retaining walls were considered. Finally, the double sheet pile was chosen as it does not require ground improvement. This sheet pile wall must be filled with soil material according to specifications packed in between the sheet pile channels. It can function as a retaining wall and can withstand the impact of a cargo ship that may collide or scrape against it. Installation by Press-in technology is recommended to help reduce the impact of soil disturbance and environmental.

5. Design of river bank protection

5.1. Design consideration factor

1) Preparation and construction activities on the land area along the river bank must not cause the existing soil to lose soil stability, such as work that causes vibration to the existing soil, landfilling for a temporary workplace and moving or standing of large and heavy machines including collecting construction materials. Currently, Press-in technology is recommended to solve these problems.

2) The sheet piles must be of good quality and produced from sources that are reliable and reputable. The materials should have cross-sections and engineering properties that meet or exceed the required specifications.

3) The wall must be stable and durable for long term (design life of 50 years, minimum). The back of revetment wall is assumed to be saturation of ground water. The water level in the river is the case of 95% of lowest water level in sailing. It may include the other uncertainty factors to increase loading that may happen in the future. For example, the villagers in some areas may fill the soil behind the wall or dredge the river in front of a wall may be deeper than design.

4) The stability factor of safety (FS) should be not less than 2.0, and wall movement should not exceed 50 mm.

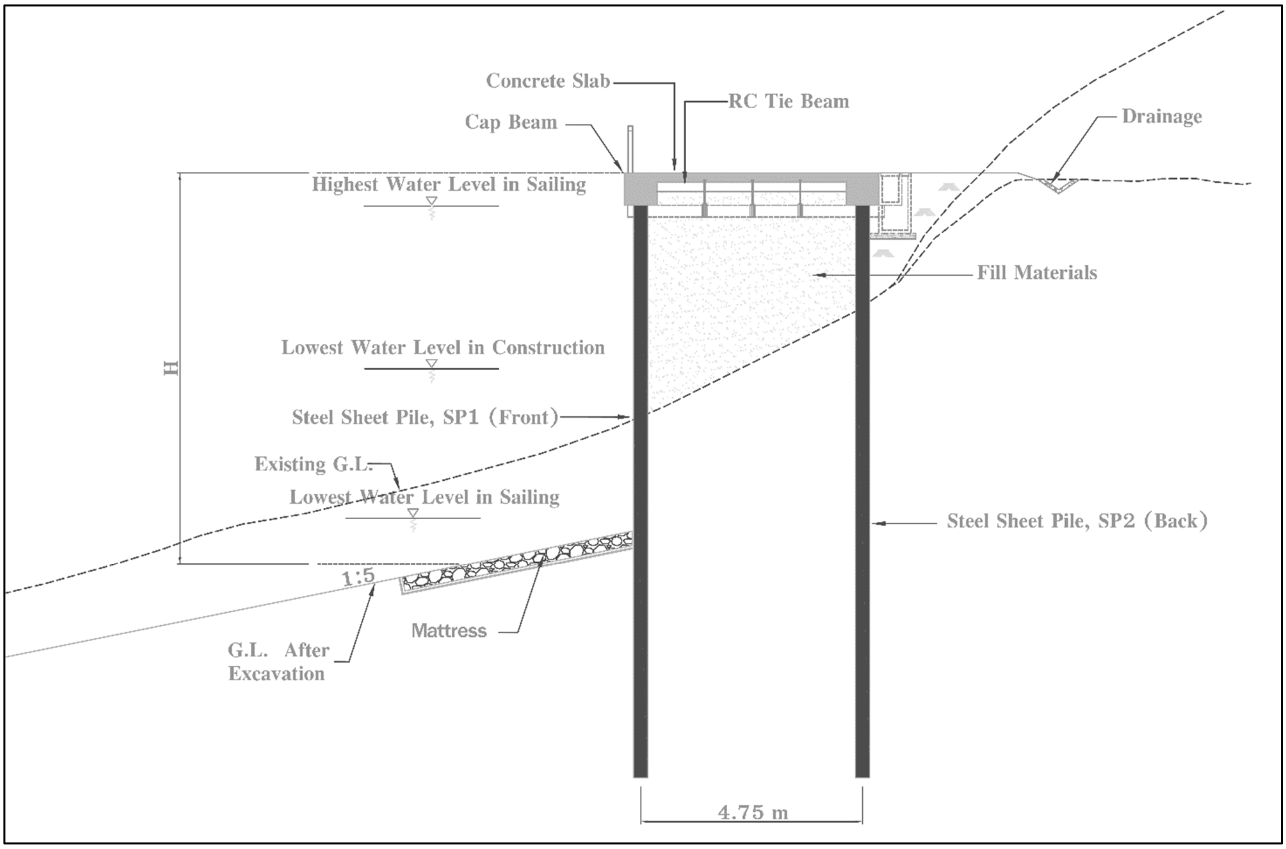

Figure 3. Typical cross-section of the double hat-type sheet pile revetment

5.2. Design

The data used for the design include the height from the cap beam to the riverbed soil in front of the sheet pile, the slope of the riverbed, soil properties, and the assumed live load on the ground surface. For the riverbed where the depth does not meet the navigation requirement, dredging is required. It is considered as an unloading condition work. Therefore, the factor of safety is known to decrease over time. The analysis and design were conducted by finite element method on Plaxis software. The wall heights (H) vary and the analysis and design were completed for 4 different heights: 4 m, 6m, 8m and 10 m. The typical cross-section of double hat-type sheet pile revetment is shown in **Figure 3.**

The cross-section of the sheet pile must be strong enough, considering that of the connection location of each sheet which is at the outer edge of the cross-section. The hat type sheet pile, as shown in **Figure 4**, is an example. Therefore, it does not reduce the strength of the sheet pile wall with the reduction factor of sectional properties, referred to as the lack of interlock integrity (The British Standards Institution, 2012). The cross-section picture shows a comparison of the bonding at the joint hat type and U type sheet piles as shown in **Figure 5**. In addition, the reference for a reduction factor of sectional properties due to the lack of interlock integrity is shown in **Table 6**.

Figure 4. Hat-type sheet pile

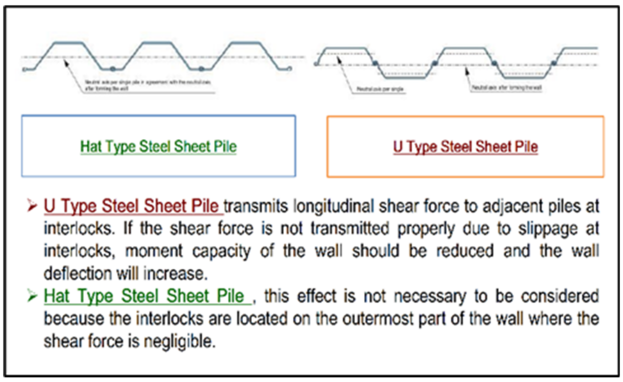

Figure 5. Interlock integrity of sheet pile

Table 6. Reference for a reduction factor of sectional properties due to the lack of interlock integrity (The British Standards Institution, 2012)

Type of U-pile unit	Number of structural support levels	Highly unfavorable conditions		Unfavorable conditions		Favorable conditions	
		β_B	β_D	β_B	β_D	β_B	β_D
Singles or uncrimped doubles	0	0.40	0.30	0.50	0.35	0.60 Pasak Case	0.40 Pasak Case
	1	0.55	0.35	0.60	0.40	0.70	0.45
	>1	0.65	0.45	0.70	0.50	0.80	0.55
Crimped or welded doubles	0	0.70	0.60	0.75	0.65	0.80	0.70
	1	0.80	0.70	0.85	0.75	0.95	0.80
	>1	0.90	0.80	0.95	0.85	1.00	0.90

β_B; Reduction factor of the section modules that account for a possible lack of shear force transmission in the interlocks

β_D; Reduction factor of the moment of inertia that account for a possible lack of shear force transmission in the interlocks

5.3. Results of the analysis

By comparing with the sectional properties of hat-type steel sheet piles of Nippon Steel Corporation, NS-SP-45H for front wall (SP1) and NS-SP-25H for back wall (SP2) as a reference, the movement and stability analysis results of the double sheet pile wall are shown in **Table 7** and the sectional analysis results of the double sheet pile wall are shown in **Table 8**. The simulated pattern of each soil group and each wall height were analyzed, and the example cases, soil group A and C, are shown in **Figure 6** to **7**.

6. Recommended length of sheet pile

The results of calculating the lengths of the sheet piles in various cases to be used in the construction are summarized in **Table 9.**

Table 7. Movement and stability analysis results of double sheet pile wall

Information						Analysis					
		Sheet Pile				Plaxis Analysis Result					
Soil Group	River Bank Height, m	Length of Sheet Pile, m	Soil at Sheet Pile Toe	Sheet Pile at Front Wall	Sheet Pile at Back Wall	Moment of Front Wall, kNm/m	Shear of Front Wall, kN/m	Moment of Back Wall, kNm/m	Shear of Back Wall, kN/m	Max Displacement, mm	FS
A (Gr 10)	4	10	Stiff to Very Stiff Clay	Hat-45 H	Hat-25 H	38.95	63.71	13.15	21.31	32.38	4.34
	6	12	Stiff to Very Stiff Clay	Hat-45 H	Hat-25 H	105.20	185.30	38.99	48.58	37.19	3.68
	8	15	Hard Clay	Hat-45 H	Hat-25 H	115.20	134.90	50.22	31.96	43.10	3.97
	10	18	Hard Clay	Hat-45 H*	Hat-25 H	218.70	164.50	57.96	82.82	45.26	4.10
B (Gr 9)	4	10	Stiff to Very Stiff Clay	Hat-45 H	Hat-25 H	55.24	53.19	13.65	18.84	37.47	3.69
	6	12	Stiff to Very Stiff Clay	Hat-45 H	Hat-25 H	129.00	144.70	58.12	25.37	47.21	2.91
	8	15	Hard Clay	Hat-45 H	Hat-25 H	126.60	76.39	65.47	53.74	55.71	2.73
	10	18	Hard Clay	Hat-45 H*	Hat-25 H	218.70	164.50	57.96	82.82	57.63	3.52
C (Gr 3)	4	12	Stiff to Very Stiff Clay	Hat-45 H	Hat-25 H	94.94	73.13	19.16	29.89	43.42	3.83
	6	15	Dense to Very Dense Sand	Hat-45 H	Hat-25 H	104.30	108.30	62.59	35.90	47.55	3.05
	8	18	Dense to Very Dense Sand	Hat-45 H*	Hat-25 H	184.00	156.20	90.45	40.85	50.50	2.47
	10	21	Hard Clay	Hat-45 H*	Hat-25 H	196.40	212.90	75.04	56.53	57.36	2.84
D (Gr 5)	4	12	Medium Stiff Clay	Hat-45 H	Hat-25 H	29.98	33.71	14.89	15.24	51.72	2.80
	6	15	Medium Stiff Clay	Hat-45 H	Hat-25 H	189.70	87.19	64.31	35.05	53.66	2.52
	8	18	Medium Stiff Clay	Hat-45 H*	Hat-25 H	170.20	101.20	100.70	54.48	66.36	2.28
	10	21	Hard Clay	Hat-45 H*	Hat-25 H	225.60	149.10	72.88	72.07	73.16	2.35
E (Gr 14)	4	12	Medium Dense Sand	Hat-45 H	Hat-25 H	51.19	53.11	12.69	13.74	47.62	2.51
	6	15	Medium Dense Sand	Hat-45 H	Hat-25 H	99.58	66.17	59.31	16.36	58.59	2.42
	8	18	Dense to Very Dense Sand	Hat-45 H*	Hat-25 H	159.30	96.30	108.70	52.84	44.49	2.44
	10	21	Dense to Very Dense Sand	Hat-45 H*	Hat-25 H	203.30	193.40	137.80	67.30	50.50	2.27

The fy of 295 MPa is for sheet pile 15 m or less, and the (*) fy of 390 MPa is for Hat-45H sheet pile longer than 15 m.

Table 8. Sectional analysis results of double sheet pile wall

Information					Checking Front Wall Sheet Pile Requirements								Checking Back Wal Sheet Pile Requirements							
					Section Modulus (SM)			Shear Stress				Result	Section Modulus (SM)			Shear Stress				Result
		Sheet Pile																		
Soil Group	River Bank Height, m	Length of Sheet Pile, m	Sheet Pile at Front Wall	Sheet Pile at Back Wall	Moment/ fy m^3	SM From Catalog m^3	Ratio of Catalog to Calc (Require >1)	Area from Catalog m^2	Shear/ Section Area	0.4fy kPa	Ratio of Shear of Section to Steel (Require <1)	Check Both Criteria	Moment/ fy m^3	SM From Catalog m^3	Ratio of Catalog to Calc (Require >1)	Area from Catalog m^2	Shear/ Section Area	0.4fy kPa	Ratio of Shear of Section to Steel (Require <1)	Check Both Criteria
A (Gr 10)	4	10	Hat-45 H	Hat-25 H	0.00013	0.00245	18.6	0.02078	3,066	118,000	0.026	Pass	0.00004	0.00161	36.1	0.01604	1,026	118,000	0.009	Pass
	6	12	Hat-45 H	Hat-25 H	0.00036	0.00245	6.9	0.02078	8,917	118,000	0.076	Pass	0.00013	0.00161	12.2	0.01604	2,338	118,000	0.020	Pass
	8	15	Hat-45 H	Hat-25 H	0.00039	0.00245	6.3	0.02078	6,492	118,000	0.055	Pass	0.00017	0.00161	9.5	0.01604	1,538	118,000	0.013	Pass
	10	18	Hat-45 H*	Hat-25 H	0.00056	0.00245	4.4	0.02078	7,916	156,000	0.051	Pass	0.00020	0.00161	8.2	0.01604	3,986	118,000	0.034	Pass
B (Gr 9)	4	10	Hat-45 H	Hat-25 H	0.00019	0.00245	13.1	0.02078	2,560	118,000	0.022	Pass	0.00005	0.00161	34.8	0.01604	907	118,000	0.008	Pass
	6	12	Hat-45 H	Hat-25 H	0.00044	0.00245	5.6	0.02078	6,963	118,000	0.059	Pass	0.00020	0.00161	8.2	0.01604	1,221	118,000	0.010	Pass
	8	15	Hat-45 H	Hat-25 H	0.00043	0.00245	5.7	0.02078	3,676	118,000	0.031	Pass	0.00022	0.00161	7.3	0.01604	2,586	118,000	0.022	Pass
	10	18	Hat-45 H*	Hat-25 H	0.00056	0.00245	4.4	0.02078	7,916	156,000	0.051	Pass	0.00020	0.00161	8.2	0.01604	3,986	118,000	0.034	Pass
C (Gr 3)	4	12	Hat-45 H	Hat-25 H	0.00032	0.00245	7.6	0.02078	3,519	118,000	0.030	Pass	0.00006	0.00161	24.8	0.01604	1,438	118,000	0.012	Pass
	6	15	Hat-45 H	Hat-25 H	0.00035	0.00245	6.9	0.02078	5,212	118,000	0.044	Pass	0.00021	0.00161	7.6	0.01604	1,728	118,000	0.015	Pass
	8	18	Hat-45 H*	Hat-25 H	0.00047	0.00245	5.2	0.02078	7,517	156,000	0.048	Pass	0.00031	0.00161	5.3	0.01604	1,966	118,000	0.017	Pass
	10	21	Hat-45 H*	Hat-25 H	0.00050	0.00245	4.9	0.02078	10,245	156,000	0.066	Pass	0.00025	0.00161	6.3	0.01604	2,720	118,000	0.023	Pass
D (Gr 5)	4	12	Hat-45 H	Hat-25 H	0.00010	0.00245	24.1	0.02078	1,622	118,000	0.014	Pass	0.00005	0.00161	31.9	0.01604	733	118,000	0.006	Pass
	6	15	Hat-45 H	Hat-25 H	0.00064	0.00245	3.8	0.02078	4,196	118,000	0.036	Pass	0.00022	0.00161	7.4	0.01604	1,687	118,000	0.014	Pass
	8	18	Hat-45 H*	Hat-25 H	0.00058	0.00245	4.2	0.02078	4,870	156,000	0.031	Pass	0.00034	0.00161	4.7	0.01604	2,622	118,000	0.022	Pass
	10	21	Hat-45 H*	Hat-25 H	0.00058	0.00245	4.2	0.02078	7,175	156,000	0.046	Pass	0.00025	0.00161	6.5	0.01604	3,468	118,000	0.029	Pass
E (Gr 14)	4	12	Hat-45 H	Hat-25 H	0.00017	0.00245	14.1	0.02078	2,556	118,000	0.022	Pass	0.00004	0.00161	37.4	0.01604	661	118,000	0.006	Pass
	6	15	Hat-45 H	Hat-25 H	0.00034	0.00245	7.3	0.02078	3,184	118,000	0.027	Pass	0.00020	0.00161	8.0	0.01604	787	118,000	0.007	Pass
	8	18	Hat-45 H*	Hat-25 H	0.00041	0.00245	6.0	0.02078	4,634	156,000	0.030	Pass	0.00037	0.00161	4.4	0.01604	2,543	118,000	0.022	Pass
	10	21	Hat-45 H*	Hat-25 H	0.00052	0.00245	4.7	0.02078	9,307	156,000	0.060	Pass	0.00047	0.00161	3.4	0.01604	3,239	118,000	0.027	Pass

The fy of 295 MPa is for sheet pile 15 m or less, and the (*) fy of 390 MPa is for Hat-45H sheet pile longer than 15 m.

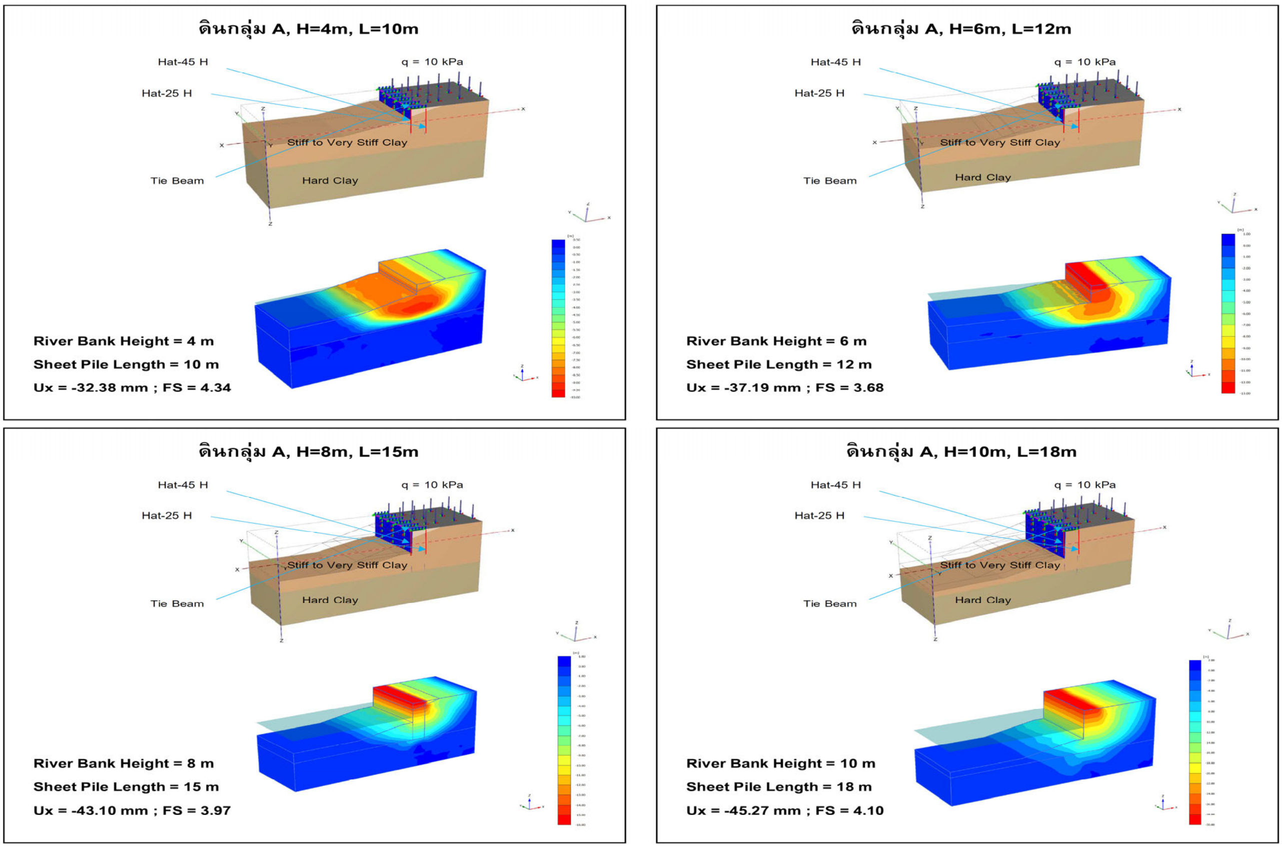

Figure 6. Model and analysis results of soil group A

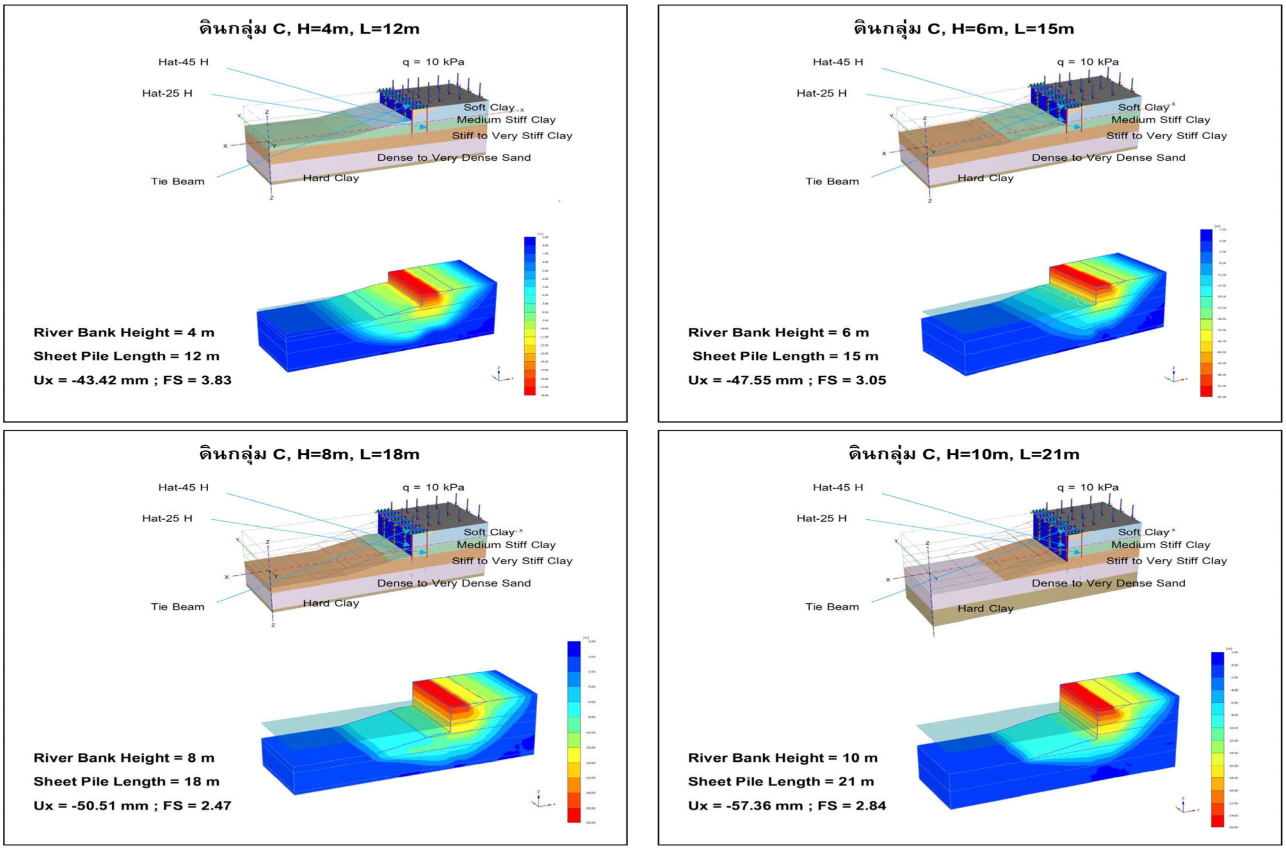

Figure 7. Model and analysis results of soil group C

Table 9. Summary of sheet pile

Soil Strength	Soil Type	Percentage of Soil Type Along the River (Approx.)	Percentage of Sheet Pile Length (Approx.)	Free Standing Height (m)	Sheet Pile		
					SP1 (Front)	SP2 (Back)	Length (m)
S (Strong)	A, B	42%	31%	4	Hat-45 H	Hat-25 H	10
				6	Hat-45 H	Hat-25 H	12
				8	Hat-45 H	Hat-25 H	15
				10	Hat-45 H	Hat-25 H	18
W (Weak)	C, D, E	58%	69%	4	Hat-45 H	Hat-25 H	12
				6	Hat-45 H	Hat-25 H	15
				8	Hat-45 H	Hat-25 H	18
				10	Hat-45 H	Hat-25 H	21

Sheet Pile SP1 (45H)	fy of Sheet Pile, MPa
Length not more than 15 m	295
Length more than 15 m	390

7 Concluding remarks

The double hat-type sheet pile revetment was designed to include widening, dredging and protecting the Pasak River bank for commercial ship transportation in the sediments of the main central alluvial plain. The double hat-type sheet pile is strong and capable of withstanding impacts from ships, and allows for a simple construction method. The new technology method for sheet pile installation, which minimizes disturbance to the existing soil and reduce environmental pollution, is the Press-in Method. The implementation of the double hat-type sheet pile revetment installed by Press-in Method for this long river bank protection project marks the first application of this technique in Thailand. **Figures 8** to **12** are the photographs of sheet pile installation in progress and construction process of double hat-type sheet pile revetment.

Figure 8. Press-in work

Figure 9. Double hat-type sheet pile wall

Figure 10. Ship transportation in Pasak River

Figure 11. Filling soil between hat-type sheet piles

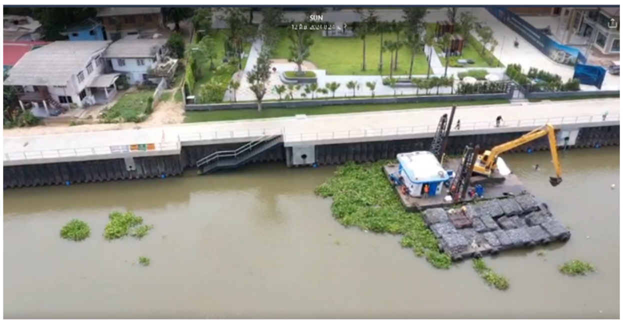

Figure 12. Completion of revetment with placing mattress at the river bed toe

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