Study for Structural Performance of Steel Sheet Piles Used for Retaining Wall

P.S. Eka[1], M. Nobuyuki[2], T. Tomoya[3]
[1]*PT Nippon Steel and Sumitomo Metal Indonesia, Indonesia*
[2]*Nippon Steel & Sumitomo Metal Southeast Asia Pte.Ltd., Singapore*
3 Nippon Steel & Sumitomo Metal Vietnam Co., Ltd., Ho Chi Minh City, Vietnam
E-mail: eka.2tb.susanto@id.nssmc.com[1]; matsui.c4d.nobuyuki@sg.nssmc.com[2]; tominaga.5xg.tomoya@vn.nssmc.com[3]

ABSTRACT: This paper describes structural performance of steel sheet pile walls based on laboratory and full-scaled field test. The steel sheet piles are widely used as a permanent and temporary retaining wall. In order to realize reliable structure of the walls, the actual performances should be evaluated properly in design especially for in case height of walls are deeper and close proximately to existing structures. From this point of view, a reduction of sectional stiffness of U-type due to insufficient transmission of shear force in interlocks are regulated in some of design standards. Depending on soil condition and restraint against slippage of interlocks, U-type should be considered reduction factor for section modulus and moment of inertia in case of composite section. On the other hand, Hat-type sheet piles fully perform the stiffness because interlocks are located on outermost surface where the shear force is negligible. The test results show the actual stiffness performed according to sheet pile shapes.
Keywords: Steel sheet pile, retaining wall, stiffness

1. INTRODUCTION

The necessity of earth retaining works in Southeast Asian countries such as Indonesia, Singapore, and Malaysia, has been increasing with the incremental of infrastructure projects such as subway train, port, bridge, and basements of building. The construction methods for these underground structures is required a high safety and reliability because accidents have a high possibility of causing fatal results. At the same time, in parallel, the improvement of productivity of construction is also considered for enhancing effectivity of economic growth.

Conventionally reinforced concrete structure has been main material for deep excavation wall. It is reinforced by steel bar or H beam so that high rigidity can be achieved and cast in place construction also can be applied. Concrete wall is also the one of affordable and versatile choice so that it is used widely in the construction.

Beside of concrete wall, Steel Sheet Pile (hereafter, SSP) is also another choice for retaining wall. SSP is connected by integrated joint clutches, it will construct a line of wall. SSP has thinner and lighter section in comparison with concrete wall. The features gives cost-effectiveness and rapid construction including easy handing at the site. SSP also is reusable member after the settlement of underground structure as a temporary structure. In addition, thanks to tight joint interlocking, SSP is able to provide water tightness. Earth retaining works can be classified into 2 usage such as for temporary and permanent usage. As temporary structure, it is applied in the underground structure to provide the soil stability from excavation stage until completion of construction. As permanent works, earth retaining works can be applied in quay wall of seaport, basement wall.

When the SSP supports earth and water pressures, bending moment and shear force is acting on sheet pile section. However, it has been discussed that these forces causes slip of interlock depending on its shape, which leads reduction of sectional performance designated, such as section modulus and moment of inertia. This can be referred as “lack of interlock integrity”, and the degree of reduction is considered as the reduction factor for sectional properties used in design. Therefore, when designing SSP retaining wall, it is necessary to consider the reduction factor properly to ensure the structural stability and safety.

In this paper, theory of reduction factor is proved. Then conducting both structural experiment and numerical analysis, degree of reduction factor were confirmed.

2. SUMMARY OF SSP

2.1 Types of SSP

In this paper, it is discussed about the sheet pile which name is Hat type steel sheet pile (hereafter, Hat type) as shown in the Figure 2 and conventional U type steel sheet pile (hereafter, U type) as in the Figure 1. As conventional steel sheet pile which is developed in 1931, U type has 400 mm width. Hat is developed in 2005, and it has 900 mm width. These sheet pile can be used as both temporary and permanent earth retaining wall. The interlocking joints of the U-type sheet pile is left-right symmetric so that it required connecting each SSP alternately reversed. On the other hand, the interlocking joints of Hat-type, with its 900mm width, has asymmetric shape so that it allows one-directional connection as shown in the Figure 3.


Figure 1 U-type sheet pile

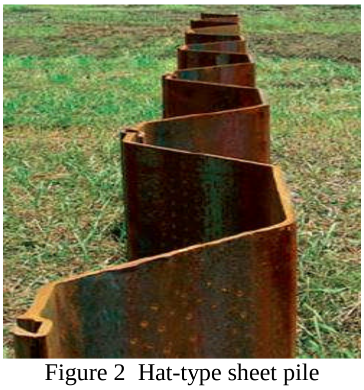


Figure 2 Hat-type sheet pile

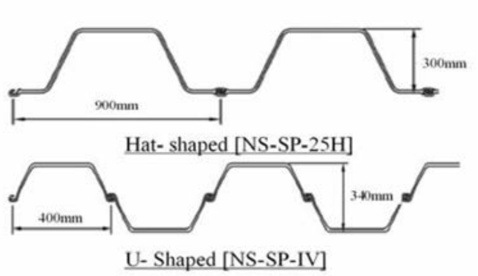


Figure 3 Comparison between Hat and U type

Table 1 Sectional Properties of HAT Type Sheet Pile

Type	Dimension			Property per meter of wall			
	Effective width	Effective height	Thick-ness	Sectional area	Moment of Inertia	Section Modulus	Unit mass
	mm	mm	mm	cm^2	cm^4	cm^3	kg/m
NS-SP-10H	900	230	10.8	122.2	10,500	902	96
NS-SP-25H	900	300	13.2	160.4	24,400	1,610	126
NS-SP-45H	900	368	15.0	207.8	45,000	2,450	163
NS-SP-50H	900	370	17.0	236.3	51,100	2,760	186

Hat type is applicable for both temporary and permanent retaining walls, and able to contribute to enhance structural safety and productivity in view of aspects below.

<Efficient pile-driving work>

Since Hat-type is more rigid than U type in terms of 1 pile, pile deformation while the pile is driven into the ground is effectively restrained, and hence even a longer pile can be driven in efficiently

<Higher structural reliability>

Since the pile joints are at the outermost part of the wall structure, the neutral axis of each of the piles coincides with that of the wall structure formed. Therefore, Hat type is able to display its structural performance under various construction conditions.

<Applicable to deep excavation and high retaining wall >

Hat type is able to provide higher section modulus and moment of inertia by combining with H shape by simple fillet welding as shown in Figure 4. The fabrication is easily done at the site. Thanks to high stiffness, it is possible to simplify additional supports such as strut and tie rod, which leads to enhance construction productivity. In addition, rapid installation is possible by using percussion hammer or vibratory hammer, compared to existing piles i.e concrete pile or steel pipe.

HAT+H is composite section, so moment of inertia is calculated as follows.

$$I = Is + As \cdot ys^2 + I_H + A_H \cdot y_H^2$$
$$I' = I / w \qquad (1)$$

I = moment of inertia of the Hat-type and H-shape per pile
Is = moment of inertia of the Hat-type per pile
As = section area of the H-shape section
I_H = moment of inertia of the H-shape section
A_H = section area of the H-shape section
y_S = distance from the neutral axis of the Hat-type and H-shape to the neutral axis of the Hat-type per pile
y_H = distance from the neutral axis of the Hat-type and H-shape to the neutral axis of the Hat-shape
I' = moment of inertia of the Hat-type and H-shape per pile wall width
w = effective width of the Hat+H pile (900 mm)

In order to specify the intermittent fillet welding, it is necessary to calculate and define the required welding ratio and leg length as shown below. The shear and flexural resistances of the sheet pile is considered in order to ensure the integrity of the Hat-pile and H-shape. In general, the welding ratio should be from 40% to 60% and the leg length should be from 6 mm to 8 mm.

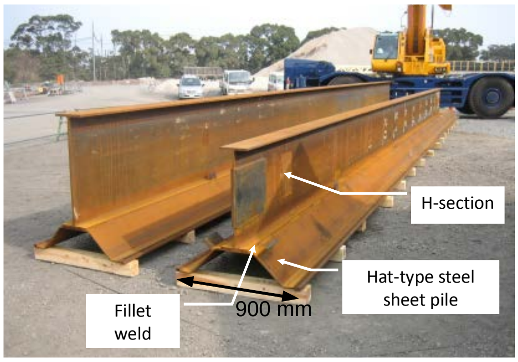


Figure 4 Outline of the Hat+H pile

2.2 Installation methods

Hat type can be installed by ordinary piling methods such as vibratory driving method and the press-in method. The vibratory diving method is the major method to reduce ground friction by vibration as shown in Figure 5 This method can shorten the driving time and drive SSP into hard ground. This method is useful not only driving but also pulling out the pile. The press-in method shown is Figure 6 is using hydraulic mechanism by grasping the middle place of sheet pile while taking reaction by holding driven piles. Driving machine is compact. It is applicable for the narrow and low clearance construction site. This method provide low noise and low vibration of construction. For hard soil layer, additional method such as water jet cutter or augering is applicable.

Figure 5 Vibro hammer (In Indonesia)

Figure 6 Silent piler (In Singapore)

3 STRUCTURAL PERFORMANCE OF SSP

3.1 Influence due to joint slippage due to shear force

Steel sheet pile must be integrated with each other with its joint interlocking for showing stiffness performance. When SSP resist the soil and water pressure, bending moment and shear force occur. These force cause joint slippage, so that SSP cannot perform actual nominal section properties i.e. section modulus and moment of inertia. This situation, so-called "lack of joint integrity" depends on the shape and joint location of SSP wall. The percentage of reduction is designated as the reduction factor. For that reason, consideration of reduction factor in the SSP design is very important to keep the structure safety and stability. In this paper, theory of reduction factor between Hat and U type is proved through structural experiment and numerical analysis and its reduction factor is confirmed.

As conventional SSP, when U type is subjected to bend due to soil pressure or other horizontal load, a large bending shear force occurs in the its interlocking joints because its interlocks are located at the center of the wall, defined as neutral axis position. In these cases, the shear force does not transmit sufficiently between the adjacent piles because the interlocking joints slip from each other, and its possessed sectional properties, the moment of inertia and section modulus of the wall, are reduced by the reduction factor.

Hat as relatively new steel sheet pile has many advantage. Beside of its 900mm width perform less number of piling than U type for rapid construction, Hat also has been proved able to perform 100% joint integrity as discussed in Eurocode. It means that the actual nominal value of stiffness i.e section modulus and moment inertia can be inputted without considering the reduction factor due to the shape factor and site condition. On the other hand, Hat-type sheet piles does not slip because interlock located on the outermost side of the wall. So, Hat-type wall is no need to consider reduction factor. Figure 7 illustrates interlocking joint behaviours both U-type sheet piles and Hat-type sheet piles.

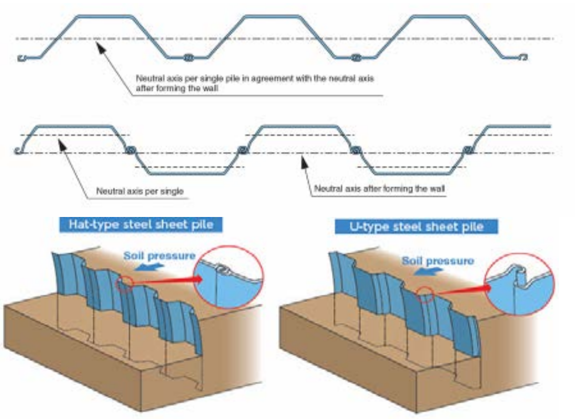


Figure 7 Theoretical behavior due to interlock integrity

3.1 Sectional Performance of Hat and Hat+H

In order to evaluate the bending resistance characteristic of the Hat-type sheet pile, a single 10H pile and two 10H piles jointed side by side were subjected to a bending test. The load-displacement curves obtained from the test are shown in Figure 8. The vertical axis represents the load converted in terms of the sheet pile width per meter. Up to the yield load calculated from material test results, the load-displacement relationships are almost the same as theoretically estimated. In addition, despite the fact that the 10H pile is thinner and has a large sectional area, it demonstrated sufficient plastic deformation performance devoid of local buckling until the total plasticization load was reached. Like the single 10H pile, the jointed 10H piles showed a similar load-displacement relationship in the bending test. Thus, it is confirmed from bending test that just as with the Hat-type sheet pile, the joint efficiency can be omitted from consideration.

The Flexural tests for Hat+H were conducted in order to verify the sectional performance under bending force as well. The sheet pile and H-shape were combined by fillet welding with a leg length of 6 mm. The flexural moment was generated by having vertical forces acting on the flange portion of the H-shape as shown in Figures 9. The vertical load acted on the upper flange of the H-shape. Figure 10 shows the relationship between the bending moment and the curvature obtained by the loading test. The curvature, ϕ, was calculated by the measured displacements at the loading point and center of the specimen. It shows that the bending moment of the Hat+H pile is almost the same as theoretical curve up to the yield bending moment of the composite section. This large section did not cause local buckling before yielding. In addition, the strain distribution in the section along the vertical direction kept the plane, and it was not discontinuous like a built-up section as shown in Figure 11. In addition, the strain curve is also equivalent to that of the calculated value of a composite wall. These results shows Hat+H can be treated as a composite section by simple fillet welding for the Hat-type and H-shape.

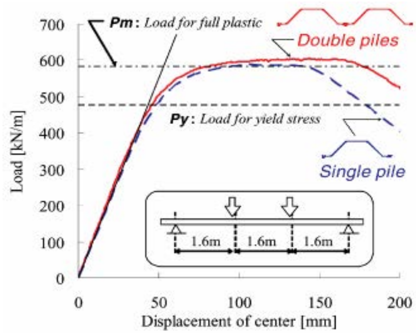


Figure 8 Bending resistance of HAT

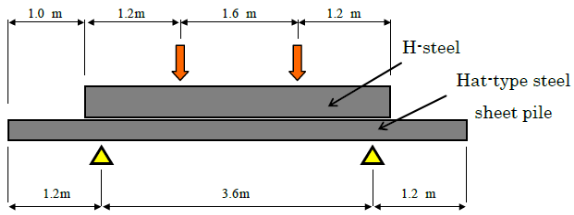


Figure 9 Outline of the flexural test

Table 2 Specimens and sectional properties

Sheet Pile	H shape (H×B×t_w×t_f)	Sectional Properties(Per 1m length) Weight (kg/m)	Moment of Inertia (cm^4/m)	Section Modulus (cm^3/m)
10H	400×200×9×12	169	88,074	2,320

H : Depth of section, B : Width of section, t_w : Web thickness t_f : Flange thickness.

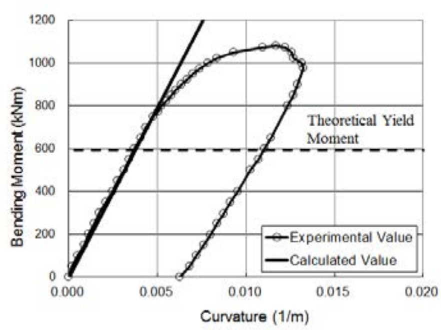


Figure 10 Bending moment to curvature

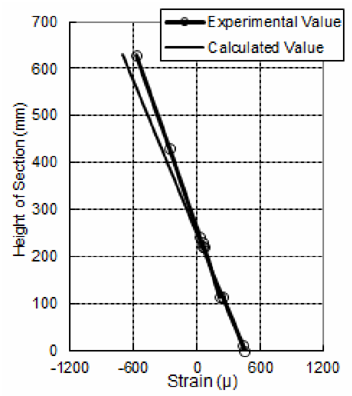


Figure 11 Distribution of strain at allowable load

3.2 Estimation of the reduction factor

In the Figure 12, there is illustration about the sectional strain distribution related the position of the neutral axis of the wall.

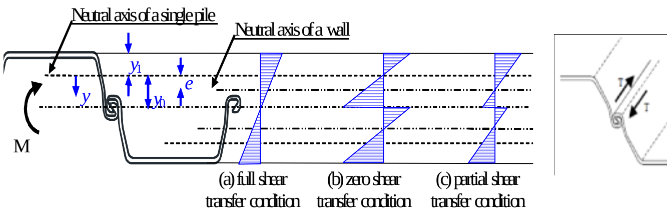


Figure 12 Illustration of relationship between the interlock slippage and section strain distribution

y_1 = the distance between the edge of the web side and the neutral axis of a single sheet pile,

y_0 = the distance between the neutral axis of a single sheet pile and the edge of the interlock side,

e = the distance between the neutral axis of a single sheet pile and the neutral axis of the wall.

The actual sectional strain distribution depends on the transmission of the shear force T in the interlock. In the full share transfer condition, the neutral axis of the wall (e=y0)(Figure 10.a). On the other hand, in the zero shear transfer condition, the neutral axis of the wall corresponded to that of a single sheet pile (e=0)(Figure 10.b). When the partial shear force transfers in the interlock, the neutral axis of the wall located within the region bounded by the full and zero shear transfer conditions (0<e<y0)(Figure 10.c).

The bending moment M is caused by the soil pressure acts on the wall, the stress σy at the distance y from the neutral axis of the single sheet pile is

$$\sigma_y = \frac{(M - 2Ty_0)}{I_1} y - \frac{2T}{A} \quad (2)$$

where I_1 is the moment of inertia of a single sheet pile, A is the sectional area of a single sheet pile.

Since the stress σ_y is zero at the center of the wall ($y = e$):

$$\frac{(M - 2Ty_0)}{I_1} y = \frac{2T}{A} \quad (3)$$

Then, the shear force T in the interlock is:

$$T = \frac{eAM}{2(I_1 + y_0 eA)} \quad (4)$$

Next, the stress σ_w occurred at the web is:

$$\sigma_w = \frac{M - 2Ty_0}{I_1}(-y_1) - \frac{2T}{A} \quad (5)$$

From (3) (4), the stress σ_w is described:

$$\sigma_w = -\frac{M}{I_1 + y_0 eA}(y_1 + e) \quad (6)$$

Thus, the moment of inertia I is:

$$I = I_1 + y_0 eA \quad (7)$$

Also, the section modulus z_w at the edge of the sheet pile web is:

$$z_w = \frac{I_1 + y_0 eA}{y_1 + e} \quad (8)$$

Furthermore, the stress σ_t at the interlock is obtained from (1) ($y = y_0$) and (3):

$$\sigma_t = -\frac{M}{I_1 + y_0 eA}(y_0 - e) \quad (9)$$

Thus, the section modulus z_t at the interlock is:

$$z_t = \frac{I_1 + y_0 eA}{y_0 - e} \quad (10)$$

In the full shear transfer condition, the neutral axis of the wall located the center of the wall ($e = y_0$). Then, the stress σ_{w0}, the section modulus z_{w0} at the web and the moment of inertia is:

$$\sigma_{w0} = -\frac{M}{I_1 + Ay_0^2}(y_1 + y_0) \quad (11)$$

$$z_{w0} = \frac{I_1 + Ay_0^2}{y_1 + y_0} \quad (12)$$

$$I_0 = I_1 + Ay_0^2 \quad (13)$$

Thus, the factor accounting for the possible reduction of the moment of inertia due to lack of shear force transmission in the interlocks β_D is defined as:

$$\beta_D = \frac{I}{I_0} = \frac{I_1 + y_0 eA}{I_1 + Ay_0^2} \quad (14)$$

Regarding the factor accounting for the possible reduction of the section modulus due to lack of shear force transmission in the interlocks β_B, there are two equations, i.e., β_w at the web and β_t at the interlock:

$$\beta_w = \frac{Z_w}{Z_{w0}} = \frac{y_0 + y_1}{y_1 + e} \times \frac{I_1 + y_0 eA}{I_1 + A{y_0}^2} = \frac{y_0 + y_1}{y_1 + e}\beta_D \qquad (14)$$

$$\beta_t = \frac{Z_t}{Z_{w0}} = \frac{y_0 + y_1}{y_1 - e} \times \frac{I_1 + y_0 eA}{I_1 + A{y_0}^2} = \frac{y_0 + y_1}{y_0 - e}\beta_D \qquad (15)$$

The section modulus is adapted on the side occurred maximum stress, which is depends on the e:

$e > \frac{y_0 - y_1}{2}$; the maximum stress occurs at the edge of the web,

$e < \frac{y_0 - y_1}{2}$; the maximum stress occurs at the interlock.

In the figure 13, it is shown about the relationship between the position of the actual neutral axis of the wall e and reduction factors β in the case of NS-SP-IV (hereafter, IV). When the neutral axis of the wall located the center of the wall ($e = y_0$), the full shear transfer condition ($\beta = 0$) is occurred. During the partial shear transfer condition, the neutral axis of the wall shifts from the center of the wall to the neutral axis as single sheet pile. The reduction factor for moment of inertia β_D decreases linearly with decreasing of e. When the neutral axis reaches the half of the effective sheet pile height ($e = (y_0 - y_1)/2$), the maximum stress side changes from the web side to the interlock side. After the neutral axis exceeds the half of the effective sheet pile height ($e < (y_0 - y_1)/2$), the reduction factor for the section modulus β_B decreases rapidly with changing from β_w to β_t. In this situation, the maximum stress at the interlock increases rapidly.

3.3 Reduction factors stipulated in design codes

In the table 3, it is shown that the reduction factors stipulated in design codes in Japan and Eurocode. In Japan, β_D as the reduction factor for the moment of inertia is set as 0.45, with no welding or crimped at each sheet pile. In Eurocode, it is set as 0.30 to 0.40, with cantilever, uncrimped, and favorable or unfavorable soil conditions.

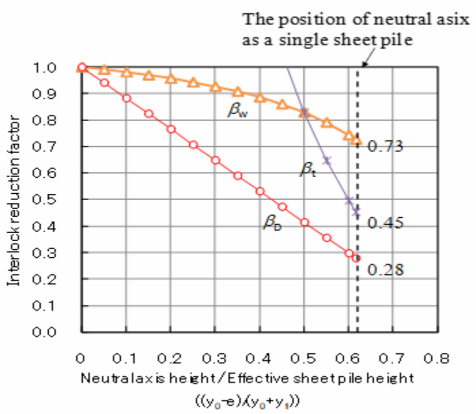


Figure 13 Relationship between e and β

Table 3 Stipulated reduction factor in some design code

		β_D	β_B	Remarks
Japan	Japan Road Association Design guideline of temporary structure	0.45	0.6	Not weld
Europe	Eurocode-3 Design of steel structures	0.30-0.40	0.40-0.60	Singles or uncrimped doubles, no structural support, unfavorable soil condition

4. STRUTURAL TEST

4.1 Test purpose

The purpose of this test is to verify the lack of interlock integrity of U-type sheet pile by comparing its deformation in actual situation.

4.2 Test method

Both of NS-SP-25H (hereafter, 25H) and IV is installed into the ground to construct cofferdam as shown in the Figure 12 then it is excavated inside as shown in the Figure 13. After that the horizontal displacement of each sheet pile wall is measured and compared between its possessed stiffness and actual deformation.

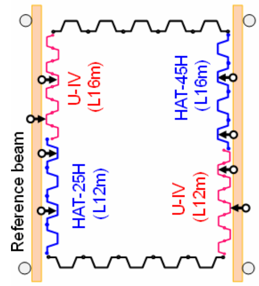


Figure 14 Construction cofferdam

Figure 15 Excavation inside the cofferdam

4.3 SSP properties

In the Table 3 it is shown about SSP type, length, and sectional properties of this test. Both IV and 25H has same 12 m length with embedded 11.1 m into the ground. Inside excavation depth is 5.8m. Possessed moment of inertia of IV is approx. 1.58 times higher than its 25H.

Table 4 SSP properties

Type		Sheet pile length (m)	Embedded length (m)	Excavation depth (m)	Moment of inertia (cm^4/m)
U-type	NS-SP-IV	12.0	11.1	5.8	38,600
Hat-Type	NS-SP-25H	12.0	11.1	5.8	24,400

4.4 Soil condition

In the Figure 14 it is shown about the relationship between the embedded pile depth and the soil level and SPT-N value. Silt and clay is exiting this test site.

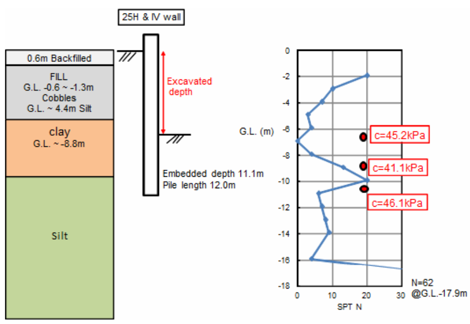


Figure 16 Soil condition

4.5 Results

In the Figure 15 it is shown about the relationship between the excavated depth and the horizontal displacement of the SSP. The displacement is obtained as the average value of three measuring methods. If a measured value is out of standard variation of three measured values, the rest two values are used to calculate the average.

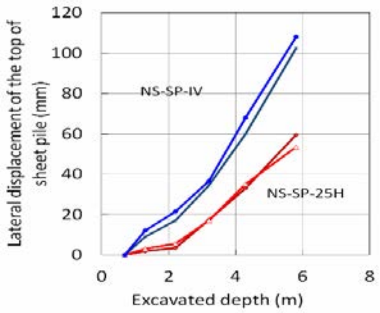


Figure 17 Relationship between the excavated depth and lateral displacement

Before the excavated depth reached -2 m, the displacement of all walls is small. After the excavated depth exceeded -2m depth, the displacement increased relatively large. Finally, the excavated depth reached -5.8m and it is shown that the displacement of the IV wall shows maximum and the displacement of 25H wall is 45% smaller than displacement of IV. It means that the actual wall stiffness composed by 25H is higher than IV even though the nominal moment inertia of 25H is 37% lower than IV as shown in Table 3. Therefore, it is said that the IV wall is occurred the lack of interlock integrity.

5. Numerical analysis

5.1 Finite Element Method (FEM)

FEM analysis by PLAXIS is carried out to estimate the lack of integrity of type IV. Firstly, the soil condition is adjusted as shown in the Table 4 in order to make corresponding the displacement of 25H by PLAXIS with that test value, because the stiffness of 25H wall is clear under full shear transfer condition. Then, the stiffness of IV wall is varied to adjust the PLAXIS result with the displacement measured in the test. When the displacement of IV obtained by PLAXIS matches the test value, this stiffness means the actual stiffness of IV wall and the reduction factor could be obtained.

Then the structure and its condition is modelled as in the Figure 17. The sheet pile is embedded into ground 11.1 m, and the excavation width is 4m. The water level is set on G.L. -1.1 m (H.W.L).

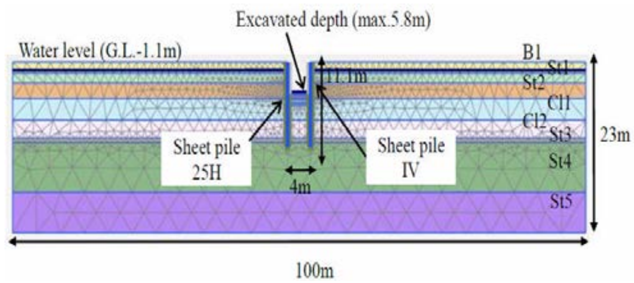


Figure 18 Overview of PLAXIS excavation simulation model

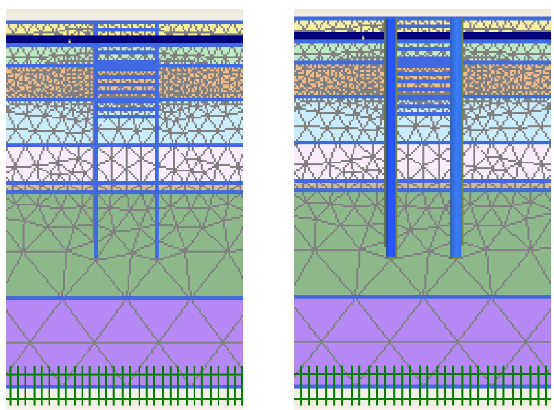
The excavation protocol is illustrated in the Figure 18. After the sheet piles are placed (Step2), excavated depth is deepened gradually (Step3), finally reach to 5.8m (Step4).

Table 7 Coefficients for δh* in medium dense sand

Thickness	G.L	Weathering grade	Unit weight	Shear strength			Mod. of elasticity		Permeability	Poisson's Ratio	Ko
				Undrained	Drained		Undrained	Drained			
				cu	c'	Φ'	Eu	E'	k		
m	m		kN/m³	kN/m²	kN/m²	deg	MN/m²	MN/m²	m/s		
1.5	0 / -1.5	Fill-1	17.0	0	0	37.0	14.0	11.7	$1.0x\ 10^{-8}$	0.3	0.40
1.3	-2.8	Fill-2	17.0	0	0	41.4	56.0	46.7	$1.0x\ 10^{-8}$	0.3	0.34
1.6	-4.4	Fill-3	17.0	0	0	34.7	28.0	23.3	$1.0x\ 10^{-8}$	0.3	0.43
3	-7.4	Clay-1	15.2	45	0	0	60.0	50.0	$1.0x\ 10^{-9}$	0.3	1.00
2.2	-9.6	Clay-2	16.1	38	0	0	60.0	50.0	$1.0x\ 10^{-9}$	0.3	0.45
0.6	-10.2	Silt-1	19.6	0	0	36.5	56.0	46.7	$1.0x\ 10^{-9}$	0.3	0.40
6.9	-17.1	Silt-2	19.6	0	0	32.5	16.8	14.0	$1.0x\ 10^{-9}$	0.3	0.46
5.9	-23.0	Silt-3	19.6	0	0	39.5	173.6	145	$1.0x\ 10^{-9}$	0.3	0.36

5.2 Results

As the results, in the Figure 19 it is shown about the deformation view in the -5.8 m excavation depth from G.L. The deformation of IV is larger than 25H. In the Figure 20 it is compared about displacement from PLAXIS with the actual test data. In -5.8m from G.L, the displacement simulated by PLAXIS is close to the test data rested 16 hours. The moment of inertia of IV is adjusted 0.4 times from its nominal value which means that the reduction factor for moment inertia is 0.4.



Step1 Step2

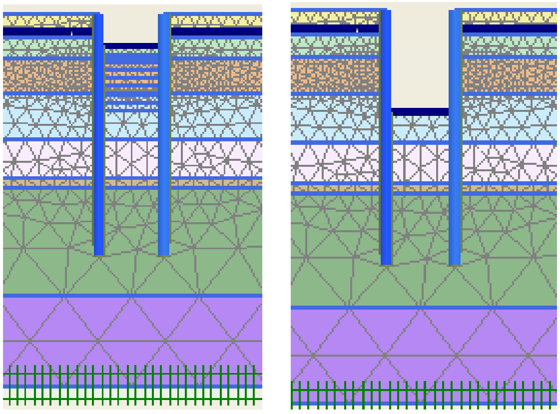


Figure 19 Excavation protocol

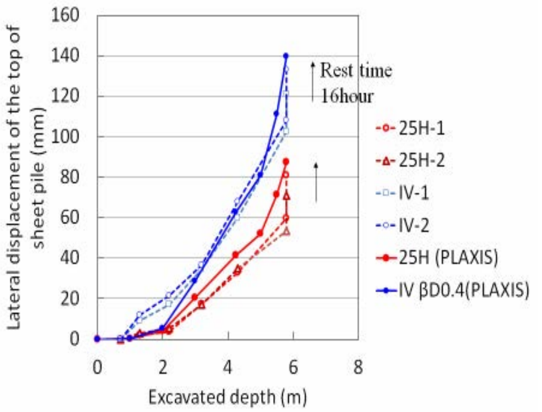


Figure 20 Comparison the PLAXIS result and Test result

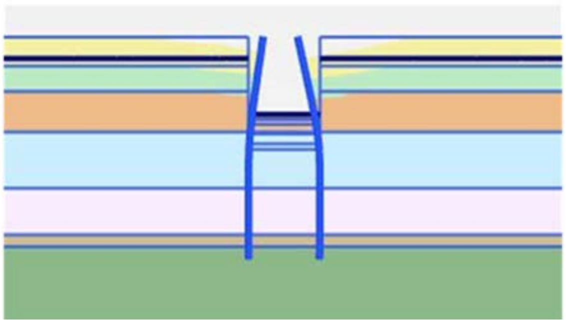


Figure 21 Deformation view of the PLAXIS result
(Left: 25H, Right: IV)

6. CONCLUSION

Through the excavation test, the stiffness between Hat-type sheet pile and U-type sheet pile is compared in actual situation. The horizontal displacement of the sheet piles wall in increasing in parallel with the incremental of excavation depth. This excavation test verified that 25H (HAT) show higher stiffness than U type IV in the same actual situation.

It is proved that U type IV sheet pile experience lack of joint integrity because displacement of the U type IV wall is larger than 25H (HAT). This lack of joint integrity condition is stated in the reduction factor for the moment inertia which is estimated 0.4 by FEM analysis (PLAXIS); this value is approximately stay in range of several standards value. For that reason, it is necessary to consider the reduction factor for U type sheet pile to ensure the structural stability and safety in steel sheet pile design stage. In other hand, it is not necessary to consider reduction factor for stiffness in case of HAT type sheet pile design.

7. REFERENCES

Harata, N. (2008). Development of Hat-Type Sheet Pile 900,edited by Tatsuta M, Kurosawa T, Nishiumi K, Taenaka S,Wakatsuki T, Miura Y, and Eda K. Nippon Steel Technical Report, Japan.

Otsushi K. et al. (2016) “Line-up Expansion of Hat-shaped Steel Sheet Pile (NS-SP-45H, 50H)”, Nippon Steel & Sumitomo Metal Technical Report, No.113, pp57-63.

Matsui et al. (2015) “Novel Compound Steel Sheet Pile for Earth Retaining Works” The IES Journal Part A : Civil & Structural Engineering

Nippon Steel & Sumitomo Metal Corporation. (2016). Product brochure, STEEL SHEET PILES.

Japan Road Association. (1999) Design guideline of temporary structure.

Eurocode3. (2007) Design of steel structures, Part5, Pilling

Susanto,Eka et al. (2017). “Study on Seismic Reinforcement Method for Coastal Dyke Using Hat Steel Sheet Pile”. HATTI (21th Annual National Conference on Geotechnical Engineering Jakarta, 7-8 November 2017). Indonesia

Vietnam National Standard. (2013): TCVN 9860:2013 Steel sheet pile structures in transportation engineering – Design requirement.