Technical Report

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Line-up Expansion of Hat-shaped Steel Sheet Pile (NS-SP-45H·50H)

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Abstract

Nippon Steel & Sumitomo Metal Corporation has developed "Hat-shaped steel sheet pile" series as a new generation steel sheet pile with improved drivability, higher structural reliability, and higher economical efficiency as compared with the traditional U-shaped steel sheet pile. The hat-shaped steel sheet pile was available in only two sizes, namely, 10H and the size 25H, which later on added with two sizes of 45H and 50H developed to provide higher sectional properties. The new sizes were released to the market in 2014. In this report, we explain the product's outline, features, construction workability, peripheral technologies, and the project conditions of 45H and 50H.

1. Introduction

We started the development of the steel sheet pile in 1929 for domestic production at the then government-owned Yawata Iron and Steel Works and began commercial production and marketing of the steel sheet pile in 1931. Since then, steel sheet pile came to be used widely in constructions such as river conservation, port and harbor, and temporary earth retaining. After that, we developed high rolling technology to realized mass production and the application technologies of designing and construction and so on. In addition owing to the high economic growth, the demand for steel sheet pile exceeded one million tons per year from 1970s to 1980s. Afterwards, owing to the improved social overhead capital plenitude ratio and the gradual decrease in the public investment, the demand continued to decrease. In recent years, the demand transitions approximately at an annual level of 600 thousand tons per year as the applications to the disasters reconstruction for the Great East Japan Earthquake and Tsunami (2011) in Tohoku region and the nationwide disaster prevention and reduction projects.

Almost 85 years have passed since Yawata Iron and Steel Works commenced steel sheet pile domestic production in 1931. During the period, a U-shaped steel sheet pile was mainly used for the wall of permanent constructions such as river and harbor port constructions. In 1997, the width of that increased from 400 mm to mainstream 600 mm, named "wide-width steel sheet pile," in order to comply with the social needs of reduction in construction cost. Later, further construction cost reduction and the application of the sheet pile to various constructions other than river and port harbor constructions came to be in demand. In order to comply with such demands, we had to develop a new high-performance steel sheet pile product with excellent construction workability, higher structural reliability, and higher economical efficiency in place of the U-shaped steel sheet pile. With such details, we developed a hat-shaped steel sheet pile with an effective width of 900 mm. Commercial production and marketing of this new product were started in 2005 after the joint development work by three steel companies of then Nippon Steel Corporation, then Sumitomo Metal Industries, Ltd., and JFE Steel Corporation.[1)]

2. Addition of 45H and 50H to Hat-shaped Steel Sheet Pile

The hat-shaped steel sheet pile has a large section with the effective width of 900 mm and has interlocking joints located on the outer edge of the wall that are asymmetric to each other. Furthermore, the profile, dimensional tolerances, chemical compositions, and the mechanical properties conform to JIS A 5523 (weldable hot rolled steel sheet piles). 45H and 50H sizes added to the existent two sizes

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in 2014 also follow the sectional properties and the quality of the hat-shaped steel sheet pile. **Fig. 1**, **Table 1**, and **Table 2** show the profile, the sectional properties, and the mechanical properties of 45H and 50H sizes.

The hat-shaped steel sheet pile has excellent construction workability, high structural reliability, and high economical efficiency.

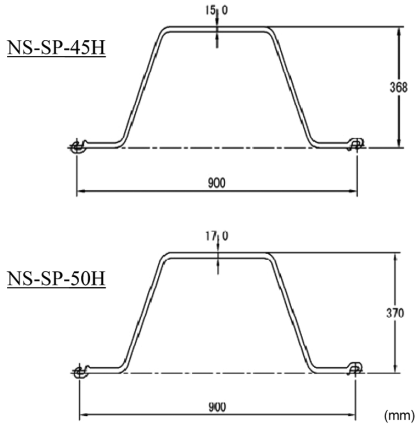

Fig. 1 Profile of hat-shaped sheet pile

Table 1 Sectional properties of hat-shaped steel sheet pile

Type	Dimension			Properties per meter of wall			
	Effective width	Effective height	Thickness	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

Table 2 Mechanical properties of hat-shaped steel sheet pile (JIS A 5523)

Standard	Yield stress (N/mm^2)	Tensile stress (N/mm^2)	Test piece standard	Elongation (%)
SYW295	295 (over)	450 (over)	1A	18 (over)
			14B	24 (over)
SYW390	390 (over)	490 (over)	1A	16 (over)
			14B	20 (over)
SYW430	430 (over)	510 (over)	1A	14 (over)
			14B	19 (over)

However, when the sheet pile performance is assessed from the viewpoint of section modulus for use as a wall, the number of sheet pile sizes in the line-up was not sufficient from the viewpoint of users. In other words, there were only two sizes of 10H and 25H whose performance is equivalent to that of conventional U-shaped sheet pile of IIw and IIIw sizes, respectively. For instance, the mixed use of the hat-shaped steel sheet pile and the U-shaped sheet pile in a same construction work caused inconveniences such as change of construction machines and the use of atypical sheet pile. Then, by adding 45H and 50H sizes whose performance is equivalent to that of conventional U-shaped sheet pile of IVw and V_L sizes, respectively, we have established the line-up of hat-shaped sheet pile covering the entire permanent construction structures. Owing to the expanded line-up, we have made it possible to show in a wide range an effective exploitation of the excellent construction workability, high reliability, and high economical efficiency of hat-shaped steel sheet pile.

2.1 Realization of excellent construction workability

In a hat-shaped steel sheet pile, both the flat arms are provided adjacent to the interlocking joints, enhancing the rigidity of the sheet pile, and thereby suppressing the deformation of the sheet pile in the soil ground in construction work. In addition, by completing the posture of the sheet pile during driving and the already driven sheet piles, we are able to make deformation modes of the adjacent sheet piles correspond in the driving work. Thereby, the penetrating resistance caused by tight engagement of the interlocking joints is suppressed. For such a reason, the hat-shaped steel sheet pile has excellent construction workability despite its large section area. Furthermore, with the release of 45H and 50H sizes, longer sheet pile can be used for construction work.

2.2 Realization of high structural reliability

As shown in **Fig. 2**, as the interlocking joints are located on the outer edge of a wall, the neutral line of a single steel sheet pile falls in line with that of the constructed wall. Therefore, the interlocking joint efficiency (decrease in the sectional performance attributed to the profile of the steel sheet pile and the location of the interlocking joints) does not need to be taken into account. Thus, the sheet pile exerts full structural reliability surely under various application conditions.

2.3 Realization of excellent economical efficiency

As shown in **Fig. 3**, the mass of the unit area of a steel sheet pile wall is reduced in comparison with that of the U-shaped steel sheet pile. Moreover, as shown in Fig. 2, benefited by the effective width enlarged to 900 mm, the number of steel sheet pile needed for construction could be reduced in comparison with that of U-shaped steel sheet pile and therefore, we are able to reduce construction cost owing to the shortened construction period.

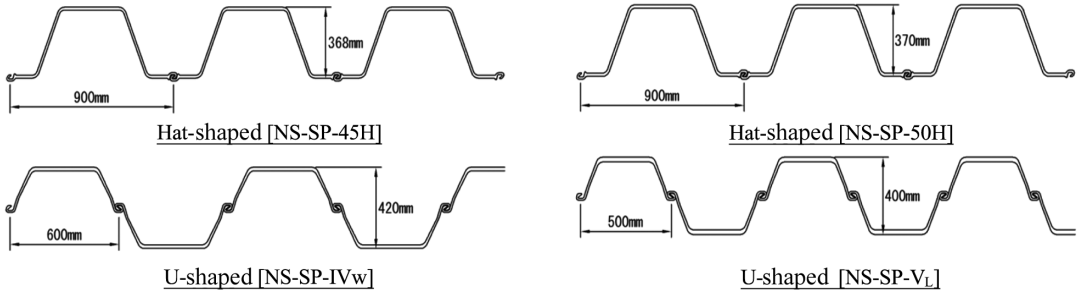

Fig. 2 Comparison of hat-shaped sheet pile and U-shaped sheet pile

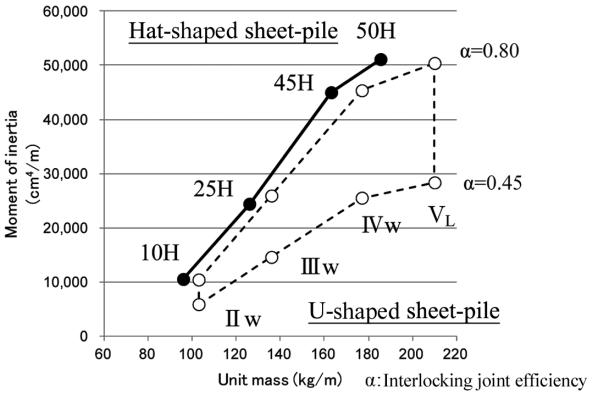

Fig. 3 Relationship between steel weight and sectional performance

3. Development of Construction Method

As for the construction method of steel sheet pile wall, a vibratory driving method and a hydraulic press-in method are mainly used. The outline of each of the driving methods and their application to the hat-shaped steel sheet pile are shown hereunder.

3.1 Vibratory driving method

The vibratory driving method (**Photo 1**) is a method in which a vibratory driving machine chucking the head portion of a steel sheet pile is excited. The vibration is transferred to the steel sheet pile and the soil ground and thereby, the steel sheet pile is driven. The driving speed is high and further, the application to hard soil ground is possible.

As for the vibratory driving method, in the case of driving conventional U-shaped sheet pile, a vibratory driving machine chucks the pile at only one point of the web (single chuck mechanism). On the other hand, in the case of hat-shaped steel sheet pile, the two-point-flange-chuck mechanism (double chuck mechanism) as shown in Photo 1, was specified as the standard construction procedure in order to transfer the vibration effectively. We also can apply the vibratory driving machine used for the conventional sheet pile driving for the hat-shaped steel sheet pile driving as it is. A double chuck device is only installed on the sheet pile chucking mechanism. As the inclination of the flange is different to each among the sizes of 10H–50H, a double chuck device for exclusive use for 45H and 50H sizes was developed newly, which is shown in Photo 1.

3.2 Hydraulic press-in method

Hydraulic press-in method (**Photo 2**[2]) is a method that drives a steel sheet pile into the ground foundation statically by taking advantage of the resistant force from the already driven steel sheet piles, which holds the counterforce in hydraulic press-in driving. The method is appropriate to construction work like the one in urban areas where low vibration and low noise construction work are required or where the construction space is confined.

In the hydraulic press-in method, a special-purpose machine for hat-shaped steel sheet pile as shown in Photo 2 is used. In the hydraulic press-in machine we also adopt one point chucking method at the web in the case of driving conventional U-shaped steel sheet pile. On the other hand, in the case of driving hat-shaped steel sheet pile, the steel sheet pile is chucked at the two locations on the sheet pile arm portions in order to transfer press-in force effectively. Hydraulic press-in machine is designed so as to chuck the sheet pile at the arm positions regardless of the size of the hat-shaped steel sheet pile of 10H–50H. So it also is possible to use the existent special-purpose machine for hat-shaped steel sheet pile in construction work. Furthermore, even to the hard ground that exceeds the water jetting auxiliary method application threshold (N>50), we successfully have developed a hydraulic press-in machine equipped with the auger as shown in **Photo 3**[2]. By this development, driving to the wider range of the ground condition has become possible.

When it is difficult to install a crane due to, for instance, confined construction space, the difficulty can be overcome by the non-

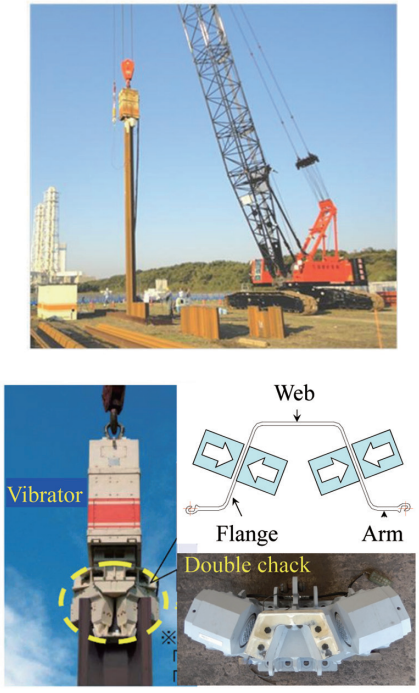

Photo 1 Driven hat-shaped sheet pile by vibratory driving

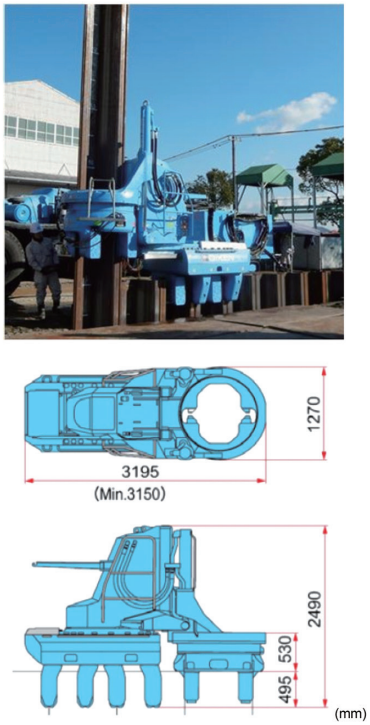

Photo 2 Driven hat-shaped sheet pile by hydraulic jacking method[2]

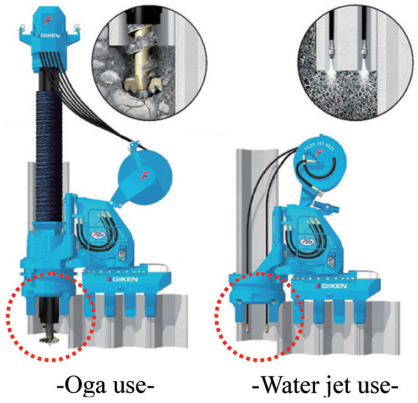

Photo 3 Hydraulic jacking method against hard foundation [2)]

Photo 4 Driven hat-shaped sheet pile by hydraulic jacking method [2)]

staging hydraulic press-in method developed by Giken Ltd. (**Photo 4** [2)]). This is an epoch-making method. In addition to the hydraulic press-in machine, a crane that holds a sheet pile in vertical direction for driving is installed in such a way as to travel on the sheet piles already driven into the ground. In addition, a carrier called pile-runner is also installed, designed to travel on the same driven sheet piles from a sheet pile stock yard to the hydraulic press-in machine. The system has been established as a method applicable to all hat-shaped steel sheet pile sizes in company with the spread of hat-shaped steel sheet pile.

4. Test for Confirming Construction Workability

Stated below is the tests conducted to confirm the construction workability prior to practical applications. They are (1) the tests of the vibratory driving method conducted in Nippon Steel & Sumitomo Metal Research & Engineering Center in Futtsu City in Chiba Prefecture and (2) the tests of the hydraulic press-in driving method conducted in the Kochi Head Office of Giken and in the Nippon Steel & Sumitomo Metal Research & Engineering Center (ditto).

4.1 Confirmation of vibratory driving method (in Futtsu City, Chiba Prefecture)

In the tests, each of the construction workability in the following steel sheet pile driving conditions was compared; hat-shaped steel sheet piles of NS-SP-45H and 50H with the length (L) of 12.0 and 25.0 m, and the wide-width steel sheet pile of NS-SP-IVw with the length L of 12.0 and 25.0 m. The sheet piles were driven by a hydraulic-type vibratory driving machine (SR-45) and electrical-type vibratory driving machines (60 kW class, 90 kW class). The tests were conducted for the cases with and without auxiliary water jetting method. To chuck steel sheet pile, a double-chuck device was used for the hat-shaped steel sheet piles and a single-chuck device was used for the wide-width steel sheet piles. In **Photo 5**, the condition of the vibratory driving and in **Fig. 4**, the ground condition of the tests and the driving time in every 1 m of driving depth is shown, respectively. Moreover, the vibratory driving without auxiliary water jetting was applied only until the ground condition of the N value of 50 was reached (applied to the 12.0 m length material) and for driving to harder ground, the auxiliary water jetting method was applied and the driving workability was assessed.

Photo 5 Condition of vibratory driving

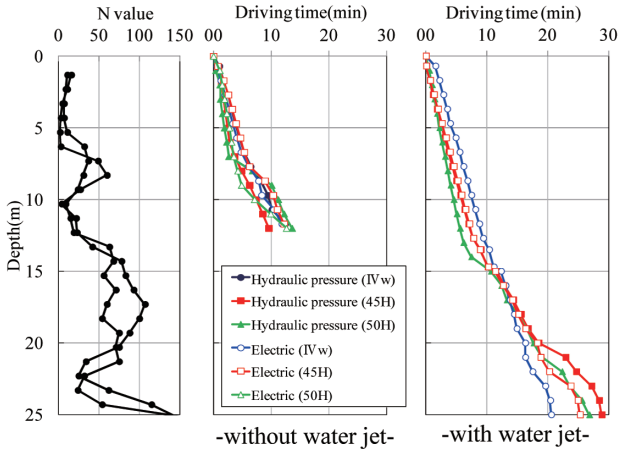

Fig. 4 Test results of vibratory driving

As for the driving time of around one steel sheet pile, some cases of slightly shorter time are noticed for wide-width steel sheet pile. However, the hat-shaped steel sheet pile has an effective width larger than that of the wide-width steel sheet pile by 1.5 times. Therefore, for a same construction length, the total driving time of the hat-shaped steel sheet piles to construct the wall is shorter, contributing to shortening of the construction period.

4.2 Confirmation of hydraulic press-in driving method (in Kochi and Futtsu)

In the tests, construction workability was compared for each of the following steel sheet pile driving conditions: hat-shaped steel sheet piles of NS-SP-45H and 50H with the length L of 12.0 and 15.0 m and the wide-width steel sheet pile of IVw with the length L of 12.0 and 15.0 m. The sheet piles were driven by a hydraulic-type press-in driving machine, and a comparison was made between the cases of with and without the auxiliary water jetting method. In **Photo 6**, the condition of the hydraulic press-in driving and, in **Fig. 5**, the ground condition of the tests and the driving time in every 1

m of the driving depth are shown, respectively.

In the tests, although there is a difference in driving time between those of hat-shaped steel sheet pile and U-shaped steel sheet pile in certain area of the driving depth, driving time was almost unchanged. This means, as mentioned earlier, that when compared for a same construction length, the total driving time of hat-shaped steel sheet piles could be shortened and it can be said that the shortening of the time contributes to construction cost reduction. Furthermore, in order to verify that this machine can press in all sizes of hat-shaped steel sheet pile, 10H–45H sizes were driven one after another continuously with satisfactory interlocking performance of joints, and the test construction could be completed without any troubles (Photo 6).

Photo 6 Condition of hydraulic jacking driving

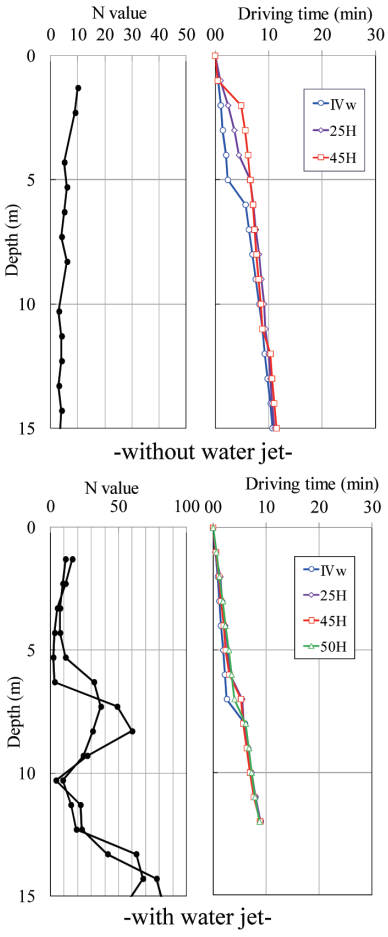

Fig. 5 Test results of hydraulic jacking driving

5. Provision of Related Technologies

5.1 Provision of heavy-duty coating

Since port and marine structures are exposed to sea water and to the conditions of varying tidal level and waves and splashes, we need to suppress the corrosion of the steel materials to maintain and manage such constructions in a proper manner to secure long-term servicing. For the purpose, a production system of heavy-coated steel sheet pile as shown in **Photo 7**, which is capable of providing 45H and 50H hat-shaped steel sheet pile with corrosion-resistant function by coating urethane elastomer in a shop, was established and has been put into practical operation.

5.2 Release to market of high strength SYW430 standard sheet pile

Since the Great East Japan Earthquake and Tsunami in 2011, the requests for liquefaction countermeasures of coastal area preservation facilities river levees, and tsunami countermeasures have grown high nationwide (particularly in the coastal areas of the Pacific Ocean side of the Tokai–Kyushu districts to cope with Nankai trough earthquake), and the demand for slope edge reinforcement by steel sheet pile and levees reinforcement by double row steel sheet pile is growing. In this field, since there is a growing need of higher yielding strength to withstand higher acting force, materials with higher strength are sought after. Therefore, compliance with the high strength standard (SYW430) of JIS A 5523 (2012) has also been made possible and further spread of the hat-shaped steel sheet pile can be promoted.

5.3 Precast-type concrete cooping

In the hat-shaped steel sheet pile, regardless of its head being tied or not, decrease in section modulus due to the interlocking joint efficiency is avoided. The head section is covered with concrete in many cases from the viewpoint of improving the landscape of the wall. Then, aiming at shortening the period of concrete covering work, Kyowa Concrete Industry Co., Ltd. has developed precast-type cooping blocks that are applicable to all sizes of the hat-shaped steel sheet pile (**Photo 8**[3]).

Photo 7 Hat-shaped sheet pile protected by heavy-duty coating

Photo 8 Precast concrete cooping of hat-shaped steel sheet pile[3]

6. Example of Actual Application

Since the start of production and marketing in 2005, hat-shaped steel sheet pile has come to be widely used for the permanent structure constructions such as of port and river (**Photo 9**) and for the temporal constructions such as earth-retaining walls and water-stopping walls. By utilizing the excellent material properties of toughness and strength of steel sheet pile and the construction workability that allows relatively easy driving even in urban areas, application of steel sheet pile to new market is steadily expanding. For instance, application like to a retaining wall of a road (**Photo 10**) and a stress insulation wall for the settlement of levees built on a soft ground foundation (**Fig. 6**). In particular, since after the Great East Japan Earthquake and Tsunami the demand has risen for the installation of the steel sheet pile wall at levees slope foot to restrain the collapse of the levees as a countermeasure against the assumed enormous seismic motion (expanded liquefaction phenomenon area). In addition, the demand for coastal and river levees reinforcement has risen in a same way, to maintain the function of the levees by installing steel sheet pile in double row at the shoulder positions when the levees is acted upon by an earthquake and tsunami (**Fig. 7**). We authors will continue to propose a client to use NS-SP-45H and 50H.

Examples of applications of hat-shaped steel sheet pile NS-SP-45H and 50H are shown hereunder.

Photo 9 Applied for river revetment

Photo 10 Applied for retaining wall

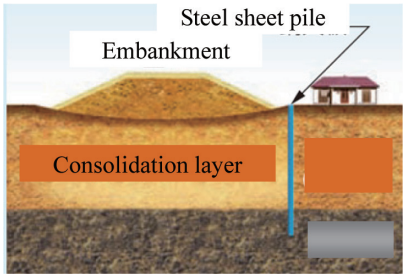

Fig. 6 Applied for mitigation of embankment settlements

Example 1 River revetment use (tide embankment) (**Photo 11** [2])
Specification of the steel sheet pile: NS-SP-45H L = 16.0 m
Date of completion: February 2015
Method of construction: Press-in method

Example 2 Retaining wall for a road use (**Photo 12**)
Specification of the steel sheet pile: NS-SP-45H L=10.0m
Date of completion: February 2015
Method of construction: Press-in method (to comply with the hard ground condition)

Example 3 For use of temporary left-in-place form earth retaining wall (**Photo 13**)
Specification of the steel sheet pile: NS-SP-45H L = 14.5 m
NS-SP-45H L = 20.0 m
Date of completion: September 2014
Method of construction: Vibratory hammering method

Example 4 Levee use (**Photo 14**)
Specification of the steel sheet pile: NS-SP-45H L = 14.0 m
Date of completion: October 2014
Method of construction: Press-in method (to comply with the hard ground condition)

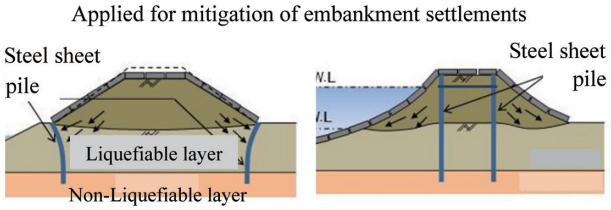

Fig. 7 Applied for coastal/river dykes reinforcement

Photo 11 Condition of application for river revetment [2]

Photo 12 Condition of application for retaining wall

Photo 13 Condition of application for temporary retaining wall

Photo 14 Condition of application for levee

7. Conclusion

The hat-shaped steel sheet piles are civil engineering products developed as a result of elaborated amalgamation of the production technology of steel sheet pile and the application technologies of designing and construction, and full-scale line-up capable of covering almost all demand of permanent constructions has been established by the release of 45H and 50H sizes. Hence, we authors determined to promote technical proposals to reduce construction cost, shorten the construction period, and so on, in a wider range of the field of application, and to contribute to the nationwide development of infrastructures by expanding the application of hat-shaped steel sheet pile.

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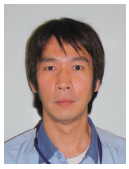

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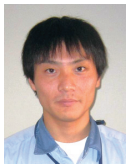

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