Technical Report

Technical Advantages of Hat-shaped Steel Sheet Pile (SP-J) for Construction in Narrow Spaces, and for Temporary Works

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Abstract

Nippon Steel Corporation developed the first hat-shaped steel sheet pile (600 mm in width as hot-rolled) in 1996. The company then developed and promoted the hat-shaped steel sheet pile (900 mm in width as hot-rolled) in 2005. Currently, this hat-shaped steel sheet pile is the leading sheet pile for permanent usage in Japan. On the other hand, regarding temporary usage, the steel sheet pile is installed and extracted several times. Therefore, it is important that the steel sheet pile is not just economical, but also robust. To date, the majority of sheet pile employed for temporary usage is U-shaped steel sheet pile (400 mm in width). However recently, the drivability and robustness of SP-J has been evaluated. The application of SP-J has gradually increased in temporary projects. In this report, main technical points are described, specifically as topics about the field test installation for the evaluation of drivability and robustness, and also the advantages in terms of construction period and cost.

1. Introduction

Steel sheet piles are construction materials generally used for civil engineering and/or architectural constructions, and are applied to permanent usage such as for harbor revetments, road retaining walls, channels, reinforcing materials for resistance to earthquakes, and so forth. They are also employed for temporary usage to resist earth and/or hydraulic pressure in the construction of structures.

Since the start of the domestic production in the government-owned Yawata Steel Works and the start of sales in 1931, U-shaped steel sheet pile, linear-shaped sheet pile, Z-shaped steel sheet pile and H-shaped steel sheet pile have been developed.[1)] U-shaped steel sheet pile has been used mainly as a general-use sheet pile. In 1996, leading other companies, the former Sumitomo Metal Industries, Ltd. (presently Nippon Steel Corporation) developed the 600 mm wide hat-shaped steel sheet piles (**Fig. 1**, Nippon Steel's original sheet pile, hereafter referred to as SP-J), and in 2005, the company started to sell the hat-shaped steel sheet pile having a width of 900 mm, the largest single hot-rolled material in the world.

Different from the conventional U-shaped steel sheet pile, since the neutral line of a steel sheet pile corresponds to the neutral line of a constructed wall, the reduction of stiffness and section modulus at the design stage that required a U-shaped steel sheet pile due to shear slip of interlocks (taking into account the efficiency of interlock shear force transmission (interlock integrity)) does not need to be considered (**Fig. 2**). Accordingly, since the weight of steel per unit wall area is reduced, and excellent in economic efficiency, currently hat-shaped steel sheet pile is dominantly used in the permanent usage construction field such as the constructions of river revetments, harbors, etc.

On the other hand, in the temporary usage field, since the steel sheet piles are installed and extracted after use, and repeatedly used

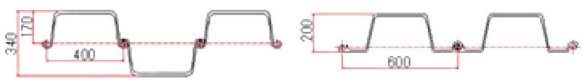

Fig. 1 400 mm in width U-shape of steel sheet pile (left) and NS-SP-J (right)

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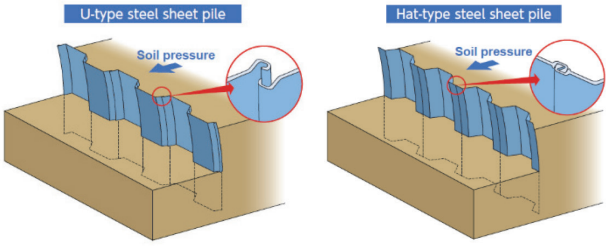


Fig. 2 Difference in behavior of steel sheet piles under earth pressure

several times, robustness in addition to economic efficiency is required from steel sheet piles. Therefore, although the use of U-shaped steel sheet piles 400 mm in width has been the mainstream up to the present, in recent years, the drivability and the robustness of SP-J have come to be appreciated; accordingly their adoption for temporary usage purposes wherein piles are repeatedly used is increasing, and some lease dealers have started to stock them.

This article explains the advantages of SP-J over the general-use purpose steel sheet piles (U-shaped steel sheet pile 400 mm in width), focusing on technical features.

2. Construction in Close Proximity Using SP-J

2.1 Features of products

The effective width of SP-J is 600 mm (**Fig. 3**), 1.5 times larger than that of the general-use purpose sheet piles in the market of temporary usage construction (400 mm wide U-shaped). Therefore, the required number of steel sheet piles is reduced, realizing the shortening of the construction period.

As mentioned previously, since hat-shaped steel sheet pile does not necessitate the reduction of stiffness and section modulus due to shear slippage of interlocks (efficiency of interlock shear force transmission = 1.0), in the comparison at the design stage of the sectional performance of the general-use purpose steel sheet piles (U-shaped III type (hereafter referred to as SP-III) and IV type (hereafter referred to as SP-IV)) as shown in **Fig. 4**, SP-J is situated in the middle between SP-III and SP-IV (Refer to the efficiency of interlock shear force transmission, 0.45 of moment of inertia of area and 0.60 of section modulus, all generally used in the design for temporary usage in the field of civil engineering provided in the Guidelines for Road Earthwork-temporary Construction Structure Engineering[2]).

2.2 Zero clearance method

Nippon Steel supplies not only products, but also advanced solutions incorporating application technologies (Construction solution brand ProStruct™). In particular, for SP-J, likewise the general-use purpose steel sheet piles, the vibration hammer method and the press-in pile installation (hereafter simply referred to as "installation") method are applicable. By using the press-in machine (manufactured by GIKEN LTD. Product name: Zero Piler)[3] exclusively developed for the characteristic products of SP-J, an installation space with zero clearance with respect to a neighboring structure in close proximity can be provided. Recognition and the establishment of the technology have been promoted by responding to the needs of installation in close proximity such as the civil engineering work of narrow channels (**Fig. 5**) and the architectural construction work in a building site that requires effective utilization, wherein steel sheet piles are unusable with the conventional method. For instance, when a 20 m × 20 m site is assumed, the effective area of a building site

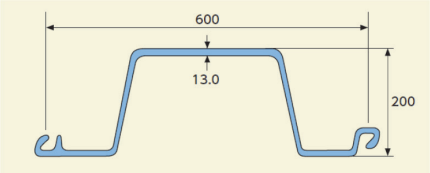
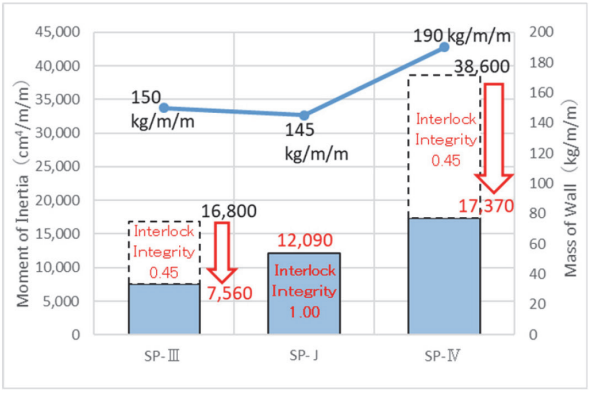


Fig. 3 Cross-sectional shape of SP-J



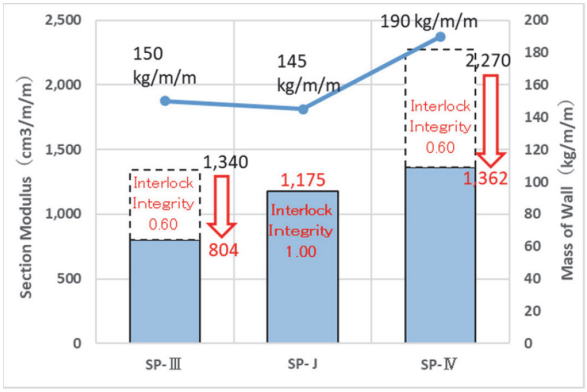


Fig. 4 Cross-sectional stiffness comparison considering interlock integrity

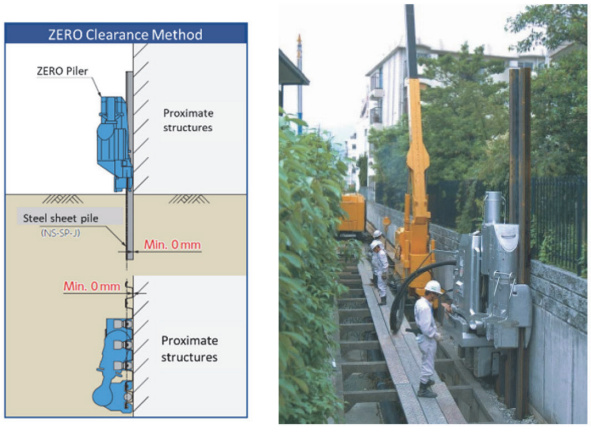
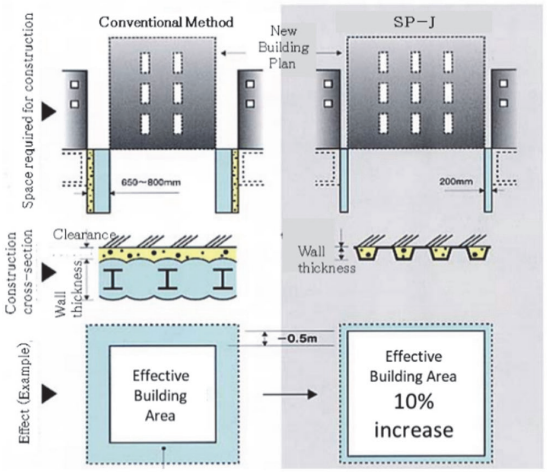


Fig. 5 Situation of construction in close proximity using a zero-piler

can be increased approximately by 10% as compared with the case of using the conventional method (**Fig. 6**).



- Site area of mid- low-rise building
- SP-J : Material 200mm, Clearance 0mm
- SMW : Material 650mm, Clearance 50mm
  →Retaining wall thickness reduced by 0.5m
- Increased area 0.5m×(20-0.5)m×4side
  →10% Increase

Fig. 6 Advantages of using SP-J for architectural retaining wall

2.3 Features of the method

SP-J has been developed as a steel sheet pile that enables the construction in close proximity, and as features for appreciation in the close proximity installation, the excellent verticality accuracy obtained in the installation work is also quoted in addition to the execution of zero clearance installation by using the aforementioned press-in machine.

To investigate the configuration characteristics of SP-J, the underground behaviors of SP-J and the general-use purpose steel sheet pile were confirmed by using an insertion type underground inclinometer.

Installation of a steel sheet pile is carried out by matching its interlock with that of the sheet pile already installed in the ground, and in the case of the U-shaped steel sheet pile, since the direction of its configuration needs to be reversed alternately one by one, the steel sheet pile under installation work tends to rotate toward its concave side with its center of rotation held at the interlocks (**Fig. 7**).

On the other hand, as SP-J is equipped with unsymmetrical interlocks, SP-J must be installed facing the same direction (Fig. 7). In SP-J, the parallel sections in the neighborhood of the interlocks resist and deter the rotation of the steel sheet pile, and accordingly, the contact and friction between interlocks is suppressed. Thus SP-J maintains high verticality accuracy in installation, and excels in installation workability.

3. Study on Repeated Use of SP-J for Temporary Usage

3.1 Technical evaluation through installation test

In order to evaluate the installation workability and durability of SP-J in repeated usage, installation tests were conducted by using the press-in machine under the actual soil conditions shown in **Fig. 8**.

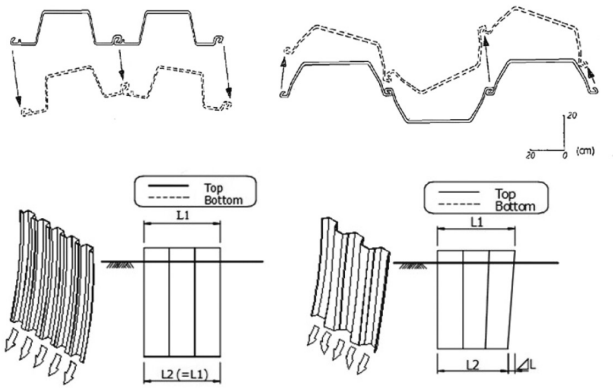


Fig. 7 Underground behavior of SP-J and U-shaped sheet piles

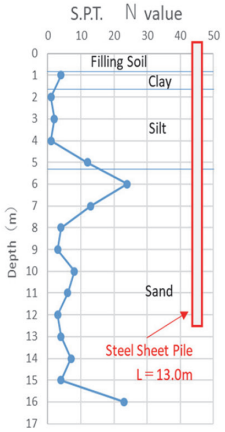


Fig. 8 Soil conditions

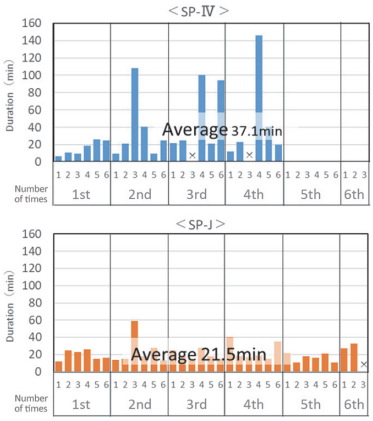


Fig. 10 Number of times and duration (minutes)

Fig. 9 Status of penetration tests

As test piles, general-use purpose steel sheet piles (SP-IV) and SP-J (6 piles per each steel sheet type, L = 13 m) were used, and the installation time and the times of repeated installation within allowable installation workability (durability) were compared.

A series of construction works consisting of installation, extraction, washing, and next installation was conducted repeatedly by using the press-in machine shown in **Fig. 9**.

Figure 10 shows the time required (duration) for the installation of each sample sheet pile at each time of repeated installation. SP-J is stable generally, the average time of which is 21.5 minutes. On the other hand, for SP-IV, the time required (duration) for installation increases along with the elapse of installation frequency, the average of which becomes 37.1 minutes. Considering that the width of SP-J is 1.5 times larger than that of SP-IV, an installation rate 2.6

times higher is realized.

In the installation tests conducted this time, the steel sheet piles were used without maintenance such as re-straightening for bend and/or camber and edge repair, which are conventionally conducted by temporary use traders. Therefore, installation was repeated under stringent conditions with regards to the repeated use of steel sheet piles. Focusing on the number of repeated use, SP-J was repeatedly used 5 times throughout, while some of the SP-IV became unable to bear installation when repeatedly used for the third time. As shown in Fig. 7, this is considered to be due to the influence of the behavior of bend and/or the camber in the underground section and the load exerted onto the interlocks. Since such load was reduced in SP-J, SP-J is considered to be advantageous in repeated installation.

From the above, although the verification of the installation condition and the soil condition, and the compilation of actual achievements are required, it is considered from the tests of this time that the robustness of SP-J in repeated use is equal to or above that of SP-IV.

3.2 Comparison study in the case of double strut

Assuming a general temporary construction work wherein the general-use purpose steel sheet piles (U-shaped) are used, a tentative design using SP-J was conducted, and advantages in design, approximate costs of material and construction, and the effect on shortening of the construction period were studied.

The design condition is shown in **Table 1**, and the design cross section structure for study is shown in **Fig. 11**.

The tentative design was based on the following assumptions: total construction elongation of 100 m, excavation depth of 5.8 m, used steel sheet pile: SP-J and SP-IV with two struts. With respect to the tentative estimation of the costs of material and construction, regarding the material cost, the SP-J lease material unit price of temporary use provided in the public document of construction material price[4] was used, and for the construction cost, the civil engineering works estimation standard issued by the Ministry of Land, Infrastructure, Transport and Tourism[5], and the piling works estimation standard by the vibration hammer method issued by the Association for the Technical Research of the Vibration Hammer Method[6] were referenced.

The result showed that, by applying SP-J, the following reductions are possible: steel weight by about 24%, number of sheet piles by 33% owing to the advantages in pile width, and as a result of these, the costs of material and construction (direct construction basis) by about 16%, and shortening of the sheet pile installation period by 28% (**Table 2**).

3.3 Study on reduction of strut

As stated in Section 2.1, since the section performance of SP-J is situated in the middle between those of SP-III and SP-IV, in the construction plan of SP-III + two strut layers, strut layers are considered to be reduced to one depending on the conditions.

Under the tentative design condition of this time, the study on the structure with an excavation depth of 5.3 m showed that, although two struts are necessary for SP-III, the reduction of one strut is possible with the use of SP-J.

Using the same condition as described in Section 3.2, the results of the trial estimation study conducted for the comparison of the direct construction cost and installation period between SP-J and SP-III are shown in **Table 3**, and its cross section of the structure with reduced strut is shown in **Fig. 12**.

The results show that by applying SP-J, the following reductions are possible: steel material weight by about 4%, number of installing sheet piles by 33% owing to the advantages in sheet pile width, material and construction cost (direct construction basis) by about 6%, and installation period by about 19%. In the actual construction work, in addition to these reductions, with the reduction of one strut, construction space is secured, and this contributes to the reduction of the construction period and cost pertaining to the construction and removing of a strut. Thus the merits such as facilitating the construction plan and suppressing the overall construction cost can be enjoyed.

4. Conclusion

In recent years, construction works accompanying the maintenance and renewal of structures are increasing, as well as other construction works are becoming complicated. Therefore, needs for construction in close proximity, the early stage development concept of SJ-P, are also growing. Furthermore, in the construction area that requires even closer proximity temporary construction work, there

Table 1 Design condition

Design code	Guidelines for temporary structure work on road earthworks
Soil condition	Sand (N = 15, φ = 30°) Wet unit weight γ = 18.0 kN/m³ Submerged unit weight γ' = 10.0 kN/m³
Surcharge	q = 10 kN/m²

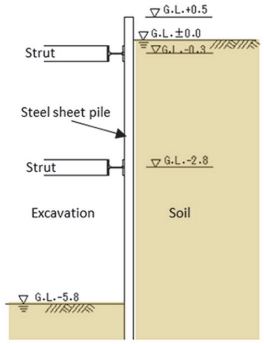


Fig. 11 Cross section of structure with double strut

Table 2 Results of the study of double strut

Steel sheet pile type	Unit	SP-IV	SP-J	
Width	(mm)	400	600	1.5 times increase
Number of pieces	(pcs)	250	167	33% reduction
Length	(m)	13.5	13.5	
Total weight	(ton)	257	196	24% weight reduction
Total installation length	(m)	3 375	2 255	33% reduction
Ratio of direct construction costs	(%)	100	84	16% advantage
Ratio of installation period	(%)	100	72	28% advantage

Table 3 Results of the study with reduced strut

Steel sheet pile type	Unit	SP-III	SP-J	
Width	(mm)	400	600	1.5 times increase
Number of pieces	(pcs)	250	167	33% reduction
Length	(m)	12.5	12.5	
Total weight	(ton)	188	181	4% weight reduction
Total installation length	(m)	3 125	2 088	33% reduction
Ratio of direct construction costs	(%)	100	94	6% advantage
Ratio of installation period	(%)	100	81	19% advantage
Number of struts	(step)	2	1	Reduce by 1 step

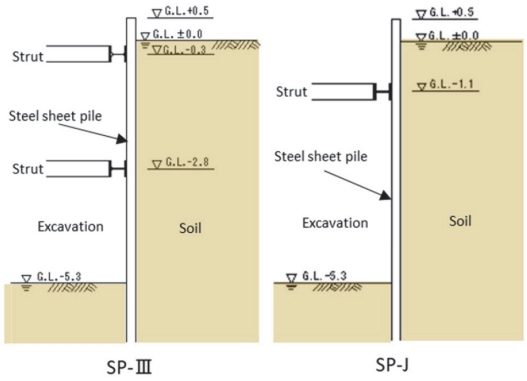


Fig. 12 Cross section of structure with reduced strut

are also other ordinary temporary construction works (not construction work in close proximity).

This time, from the results of the installation tests, not only the reduction of construction cost and shortening of the construction period by using SP-J, but also the robustness as well and the durability to withstand repeated use have been highly evaluated.

Hereafter, we are determined to propagate and expand the method by utilizing SP-J not only in construction work in close proximity, but also in the field of general temporary construction work for the purpose of reducing the total construction cost and shortening the construction period with the aim of contributing thereby to the social infrastructure development.

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