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Technical Report

Approach for Expansion of Use of HAT-Type Steel Sheet Piles in Southeast Asia

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Abstract

The use of HAT-type steel sheet piles is increasing with the development of overseas infrastructure. In order to contribute to effective construction and carbon-neutrality, the applicability and value of HAT-type steel sheet piles have been locally established, thus creating a foundation from which the value for clients and society can be maximized. This report presents these approaches and examples of solutions applied to Southeast Asia, especially Singapore.

1. Introduction

Currently, the world is facing various crises such as the new coronavirus infection (COVID-19), the Russian-Ukrainian crisis, and an increase in natural disasters due to climate change. In terms of overseas infrastructure development, demand remains high particularly in ASEAN countries in line with their economic growth. However, there is a shortage of construction workers and construction materials, and the cost of the construction materials is rising sharply. Under these circumstances, it is necessary to improve construction productivity and realize carbon neutrality.

Nippon Steel Corporation is developing the application of high-performance construction products such as HAT-type steel sheet piles and HAT+H steel sheet piles (HAT-type and H-shape combined high stiffness steel sheet piles) in overseas countries. Under the circumstances wherein the needs of local customers such as clients, design consultants and construction companies, the design standard, the ground conditions, and the trend in use of the already widely spread construction materials that are all different from those of Japan, the recognition of customers has advanced, and active use is in progress owing to our efforts of verifying the local use value, obtaining the comprehension of customers, and setting up the usage environment properly for application (for example, see: **Fig. 1**). This report presents the case of one approach for the expansion of use of HAT-type steel sheet piles in Singapore.

2. Theme in Expansion of Use of HAT-Type Steel Sheet Piles

2.1 Features of HAT-type steel sheet piles

HAT-type steel sheet piles are hot-rolled steel sheet piles, and are 900 mm in width, the largest in the world. As shown in **Fig. 2**, since

Fig. 1 Application of HAT-type steel sheet pile on temporary retaining wall in Singapore

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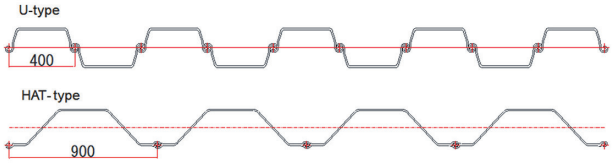

Fig. 2 Comparison of steel sheet piles between HAT- and U-type

Table 1 Sectional properties of HAT-type steel sheet piles

Type	Dimension			Per 1 m of pile wall width			
	Effective width (mm)	Effective height (mm)	Thickness (mm)	Sectional area (cm^2/m)	Moment of inertia (cm^4/m)	Section modulus (cm^3/m)	Unit mass (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

the width of HAT-type steel sheet piles is larger than that of the 400 mm–600 mm of conventional U-type steel sheet piles, the number of piles to be installed is reduced. Furthermore, due to its hat-like shape, the interlock joints are positioned on the outermost edge line of the wall, and therefore, since the neutral axis of the steel sheet pile agrees with the neutral axis of the wall, the deterioration of the sectional properties due to poorer efficiency of interlock shear force transmission considered in U-type steel sheet piles does not need to be taken into account. HAT-type steel sheet piles are able to exert their sectional properties by 100%, and due to such merit, the construction of an earth-retaining wall having high structural safety is realized. Additionally, as compared with the U-type steel sheet pile having equivalent sectional properties, the weight of the steel material can be reduced by approximately 30%, and therefore, together with the effect of shortening the construction period realized by the reduction of the number of installations, the reduction of construction cost is also realized, and the needs for productivity enhancement in Singapore can be met. **Table 1** shows the sectional properties of HAT-type steel sheet piles.

2.2 Current situation of utilization of steel sheet piles in Singapore and challenges in expansion of use of HAT-type steel sheet pile

In Singapore, steel sheet piles are used as temporary earth-retaining material required for the construction works of underground railways, foundation works in building construction, canal expansion works, and so forth. There are no steel sheet pile manufacturing companies in the country, and all steel sheet piles are imported, the majority of which are the 400 mm wide U-type steel sheet piles manufactured in China, Korea, and Thailand. Until 2014, HAT-type steel sheet piles manufactured by Nippon Steel had not been supplied. However, upon the introduction of the Eurocode that provides the efficiency of interlock shear force transmission[1] to the country as the design standard, Nippon Steel started the full-scale expansion of the use of HAT-type steel sheet piles. To secure the safety of the earth-retaining structure, the Building and Construction Authority, the construction supervisory authority of public works, stringently set the lateral displacement on a design basis (0.5% at the smallest of the excavated depth)[2]. From the perspective of feasibly achieving this requirement, HAT-type steel sheet piles are superior to U-type steel sheet piles in that the prescribed sectional properties are fully exerted definitely.

In Eurocode, in addition to the design concept of the efficiency of interlock shear force transmission, the efficiency of interlock shear force transmission of U-type steel sheet piles corresponding to solid conditions is shown. In Singapore as well, the efficiency of interlock shear force transmission is provided in the Singapore National Annex to Eurocode,[3] with no provision for HAT-type steel sheet piles. For the structural design in a country which has no recognition of HAT-type steel sheet piles, in order to obtain appropriate appreciations about the sectional properties, it was necessary to verify with data that, for HAT-type steel sheet piles, considerations regarding the efficiency of interlock shear force transmission are not necessary. Additionally, in Singapore, the responsibility and the authority of designers are influential, and even after 2015 when the Eurocode was introduced, there have been cases in which the efficiency of interlock shear force transmission of U-type steel sheet piles was not taken into consideration as a long-standing practice. Accordingly, in the comparison of HAT-type steel sheet piles with U-type steel sheet piles, it was necessary to show the difference in the efficiency of interlock shear force transmission.

Furthermore, for the pile installation (hereafter referred to simply as installation), local construction companies were skeptical about the installation workability of HAT-type steel sheet piles since their width is larger than that of U-type steel sheet piles, and the surface area per one pile becomes larger. The skepticism stemmed from the fact that in the marine clay which specifically exists in the country, the peripheral frictional force supersedes as a resistance force in installation, and thereby, shortening of the construction period corresponding to the reduction of the number of installed piles cannot be obtained. To overcome the skepticism, it was necessary to verify that, since HAT-type steel sheet piles have high stiffness, it is possible to suppress material deformation in installation, and to execute efficient and fast installation, and to show the value obtainable from such.

Taking the above into consideration, for the purpose of verifying the excellent structural performance and the installation performance of HAT-type steel sheet piles, and obtaining customer comprehension of their merit, Nippon Steel conducted a structural test and an installation test in Singapore.

3. Approach for Expansion of Use of HAT-Type Steel Sheet Piles

3.1 Approach for obtaining comprehension of merit in use of HAT-type steel sheet piles

3.1.1 Flexural test of HAT-type steel sheet pile wall

In order to evaluate the flexural resistance characteristics of HAT-type steel sheet piles, and to verify that the efficiency of interlock shear force transmission is 1.0, as shown in **Fig. 3**, a four-point flexural test was conducted on a wall consisting of two HAT-type steel sheet piles (NS-SP-10H) interlocked with each other. To secure the objectivity of the result, and to incorporate the results into the local design, the test was conducted under the direction of persons with relevant knowledge and experience of steel structure design in the country. **Figure 4** shows the experimental load-deflection

Fig. 3 Outline of flexural test of HAT-type steel sheet pile wall

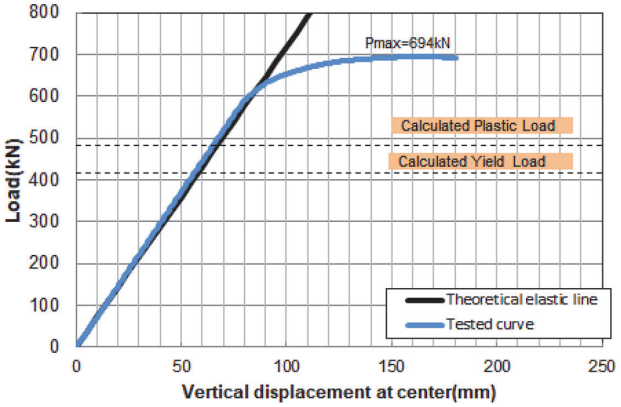

Fig. 4 Experimental load-deflection curves

curves. It is confirmed that the stiffness of the wall is equivalent to the calculated value with the efficiency of interlock shear force transmission taken as 1.0, and it is confirmed that sufficient plastic deformation performance is obtained because both the yielding load of the wall as a whole calculated from the material strength and the overall plastic deformation load are attained without producing local buckling.

3.1.2 Lateral loading test of the steel sheet pile wall

The efficiency of interlock shear force transmission of U-type steel sheet piles provided in the Singapore National Annex has not been verified in the soil conditions in Singapore. Therefore, a lateral loading test was conducted[4] in order to compare the behaviors of HAT-type steel sheet piles and U-type steel sheet piles, and to calculate the efficiency of interlock shear force transmission of U-type steel sheet piles actually installed in the local soil.

Figure 5 shows the outline of the test. Two horizontal type jacks are installed between the walls of HAT-type steel sheet piles (NS-SP-25H) and U-type steel sheet piles (NS-SP-IV), and lateral loads were applied to both sheet pile walls simultaneously. On each sheet pile, a number of strain gauges were installed in the cross-sectional direction and in the depth direction to monitor the strain distribution in the cross-sectional direction, and to calculate the efficiency of interlock shear force transmission.

Figure 6 shows sheet pile walls after lateral loading is applied. The moment of inertia without consideration of the efficiency of interlock shear force transmission is 38 600 (cm^4/m) for IV type, and

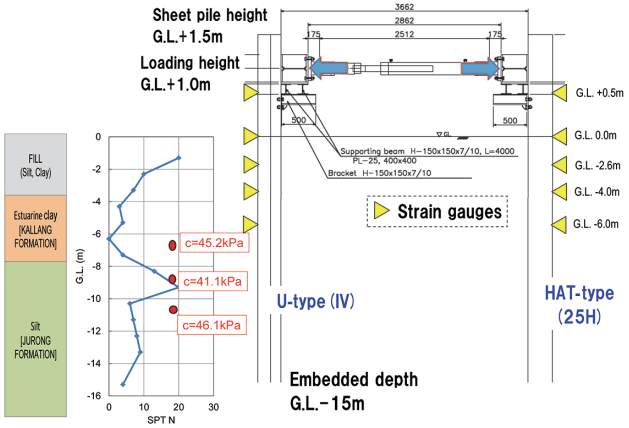

Fig. 5 Outline of lateral loading test

Fig. 6 Sheet pile walls after lateral loading test (Left: U-type, Right: HAT-type)

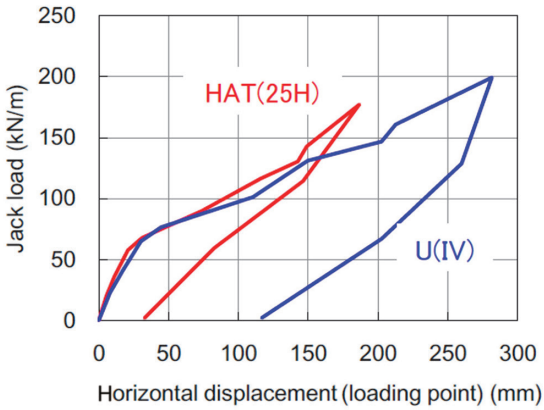

Fig. 7 Experimental lateral load per 1 m wall width and lateral displacement

24 400 (cm^4/m) for 25H. Although the value of the IV type is exceeded, it is found that in reality the IV type wall inclines more acutely. Additionally, **Fig. 7** shows the relationship between the lateral load per 1 m wall width (the sum of the load values indicated by the two load cells) and the horizontal displacement. With this, it is confirmed that the flexural stiffness of the IV type actually exhibited is equivalent to or less than that of NS-SP-25H. Furthermore, the efficiency of interlock shear force transmission of the IV type analyzed and calculated based on the strain gauge data is about

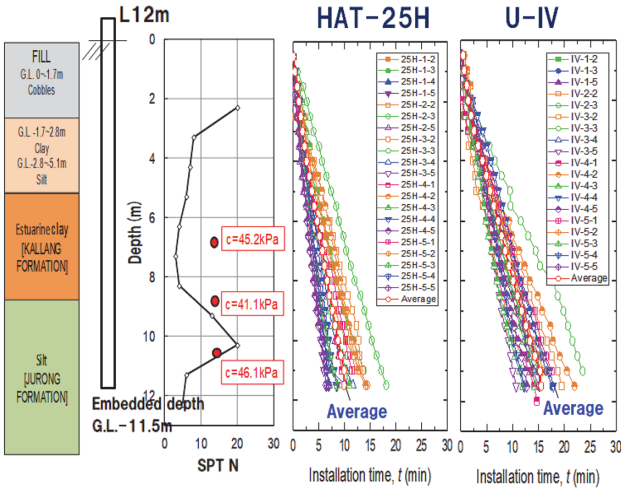

Fig. 8 Soil conditions and installation time for piling test
●Pile No. ▲Repeted number of installation

0.3 – 0.4, and the validity of the value provided in the Singapore National Annex is verified (0.3 – 0.4 under the condition of without any restraint).

3.1.3 Sheet pile installation test

In order to verify the installation performance of HAT-type steel sheet piles, an installation test was conducted on the marine clay soil of the country. The installation method was in accordance with the actual method taken for sheet piles in the country, and the press-in installation method that allows for low noise and vibration and is used in densely populated urban areas was applied. Furthermore, based on the result of hearing from the local construction companies, repeated installation tests were conducted taking into consideration the actual state of repeated use of steel sheet piles, and thus in addition to the measurement of the installation rate, the durability of steel sheet piles was investigated. For comparison purposes, five steel sheet piles of each of the U-type (NS-SP-IV) and HAT-type (NS-SP-25H) were prepared, and were installed, each pile being interlocked with each other.

Figure 8 shows the soil conditions and the installation times. It is confirmed that the installation time per each of the HAT-type steel sheet piles is equivalent to that of the U-type steel sheet piles. This shows that, since the width of a HAT-type steel sheet pile is 2.25 times larger than that of a U-type steel sheet pile, a steel sheet pile wall of the same width can be constructed in about half the installation time. In addition, within the range of the number of installations repeated for inspection, no remarkable deformations were produced in the interlock joint and the main body, and it was confirmed that a constant installation rate is maintained. It was also verified that HAT-type steel sheet piles are applicable as temporary use steel sheet piles in the country.

3.2 Approach for improvement of usage environment and application examples

In order to obtain comprehensive recognition of the abovementioned approaches, we have participated in the technical seminars sponsored by the local public institutions and academic institutions, and have disclosed the verified data. In addition, a new press-in installation machine for HAT-type steel sheet piles was developed in cooperation with a construction work machinery manufacturer and

Fig. 9 Application to canal expansion

Fig. 10 Application to port & harbor

introduced, and the full arrangement of design and construction manuals was established. A scheme that enables timely supply of HAT-type steel sheet piles to construction sites was also launched.

In this way, Nippon Steel not only sells steel products, but also provides comprehensive value engineering services such as shortening of the construction period that contributes to the reduction of CO_2, implanting in the country the use value obtained through structural rationalization, and further establishes the surrounding condition that facilitates customer adoption.

As a result of such efforts, the application case of HAT-type steel sheet piles in the country is increasing. **Figure 9** shows the case of application to canal expansion work in a narrow area. HAT-type steel sheet pile was appreciated in that the prescribed cross-sectional performance was certainly exerted in spite of the apprehensions over the possible influence of excavation on already existing structures. **Figure 10** shows an example of application to port and harbor construction, wherein, for its canal construction having a long construction distance, the rapid construction to be realized by the width of 900 mm of HAT-type steel sheet piles and the durability were appreciated, and HAT-type steel sheet piles were employed. HAT-type steel sheet piles were used several times repeatedly in this project, and, diverted to other projects afterwards. Thus, the temporary use like conventional U-type steel sheet piles is penetrating gradually. Further, based on the achievements in Singapore, cases of employing HAT-type steel sheet piles are growing in other Southeast ASEAN countries.

4. Conclusion

The applicability of Nippon Steel's HAT-type steel sheet piles to the local soil conditions has been confirmed through construction tests and actual projects. In order to clarify this worthiness, the products were registered in Singapore and Japan under the trademark of NSHAT™. Hereafter, we are determined to provide high-value-added solutions to specific needs, and thereby to respond to societal and customer needs not only in Singapore, but also in other ASEAN countries such as Vietnam and Thailand.

References

1) EN 1993-5 "Eurocode 3 Design of Steel Structures"
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