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Approach to Development of Overseas Construction Steel Product Market in the Civil Engineering Field

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Abstract

Approach for developing overseas construction steel product market in civil engineering field are now being focused on our competitive, proprietary products, "high-end products". Hat + H piles, sheet-pile cells and Sat-in Pile Foundation as the representative high-end products are introduced along with their application to actual projects.

1. Introduction

With the growth of developing countries, demand for energy and infrastructures continues to expand and such demand for construction is expected to increase hereafter as well. To date, Nippon Steel & Sumitomo Metal Corporation has continued to tackle the development of the overseas steel construction market mainly based on ODA related projects. In 2011, the company built a steel pipe mill, NPV (Nippon Steel & Sumikin Pipe Vietnam), in Phu My in South Vietnam and has established a stabilized overseas supply system.

Nippon Steel & Sumitomo Metal is currently promoting the market development of the demand for high-end products selectively based on utilization of its technologies, the products of which are competitive overseas. This article reports the approach to the development of the overseas market so far and the actual results obtained thereby as to (1) Hat + H piles, (2) Sheet pile cells and the (3) Sat-in pile foundation construction method, using the high-suitability products of Nippon Steel & Sumitomo Metal, namely Hat-type steel sheet piles, flat steel sheet piles and, steel pipe piles with internal ribs.

2. Hat + H Piles [1, 2)]

2.1 High rigidity sheet piles excellent in economy and workability: Hat + H piles

The Hat + H pile is a new type of sheet pile created through the combination of Hat-type steel sheet piles 900 mm in width and H shape steel (**Photo 1**). The features of the Hat + H piles are stated below.

1) Applicable to deepwater revetment, quay walls and large-scale earth retaining that require high rigidity that Hat-type steel sheet piles solely cannot provide, but which is made possible with the combined use of H shape steel.
2) Possible to conform to any required cross-sectional performance and to select a section of high economic efficiency owing to the extensive variety of H shape steel.
3) On-site welding and fabrication of Hat-type sheet piles and H shape steel are possible and thereby reduction in production cost and transportation cost is possible.
4) High rigidity of the Hat + H sheet piles that possess excellent workability even in the case of long sheet piles.

2.2 Cross-sectional performance of Hat + H piles

The cross-sectional performance of Hat + H pile is estimated as one of the composite cross-sections of the Hat-type steel sheet pile and the H shape steel (**Fig. 1**).

Moment of inertia of area:

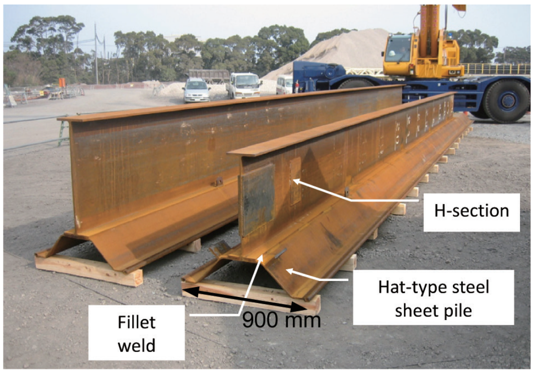

Photo 1 Outline of the Hat + H piles

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$$I = I_S + A_s \cdot y_S^2 + I_H + A_H \cdot y_H^2$$

where

I : Moment of inertia of area of a Hat + H pile
I_S: Moment of inertia of area of a Hat-type steel sheet pile
A_s : Cross-sectional area of a Hat-type steel sheet pile
I_H: Moment of inertia of area of a H shape steel
A_H: Cross-sectional area of an H shape steel
y_S: Distance between the center of gravity of the Hat-type steel sheet pile and the neutral axis of the Hat + H pile
y_H: Distance between the center of gravity of the H shape steel and the neutral axis of the Hat + H pile

Table 1 shows an example of the cross-sectional performance of Hat + H piles. A Hat-type steel sheet pile and an H shape steel are fabricated by intermittent fillet welding. The fillet welding leg size and the welding length are determined by the combination of the Hat-type steel sheet pile and the H shape steel used; however, generally the integration of the sections is secured with a fillet welding leg size of 6–8 mm and a welding length of 40–60% over the entire length.

(1) Actual size flexural test of Hat + H piles

In order to confirm the cross-sectional performance of Hat + H piles, an actual size flexural test was conducted. The outline of the experiment is shown in **Fig. 2** and **Table 2**. In **Fig. 3**, the relationship between the bending moment and the curvature obtained from the result of the test is shown. The figure shows that the experimental values agree with the calculated values up to the yielding strength level. Accordingly, it was confirmed that a Hat + H pile can be evaluated as a composite cross-section.

2.3 Fabrication of Hat + H piles

A Hat-type steel sheet pile and an H-shape steel are fabricated to a single pile with intermittent fillet welding. Therefore, correction work is not required and the welding operation can be rendered sufficiently at the construction site, not necessarily in a fabrication shop. Furthermore, as shown in **Photo 2**, welding operation can be rendered at two locations simultaneously which serves the purpose of preventing the torsional deformation of the entire pile. The fabrication work in a yard near a construction site reduces the labor of transportation and storage greatly.

2.4 Execution of Hat + H pile construction

(1) Construction execution method

Construction of Hat + H pile is possible with conventional ma-

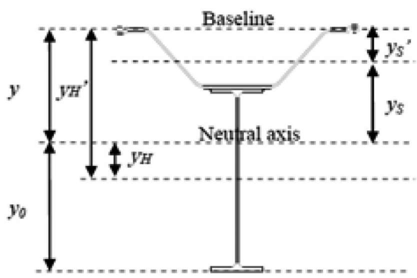
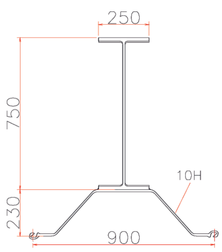


Fig. 1 Calculation of Hat + H piles

Table 1 Example of the cross section and property of Hat + H piles

	10H + H750 × 250 × 12 × 19
Cross section (unit: mm)	
Weight (kg/m)	256
Section modulus Z (cm³/m)	6 770
Moment of inertia I (cm⁴/m)	379 000

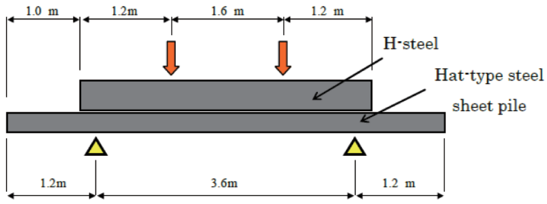


Fig. 2 Outline of the flexural test

Table 2 Specimens and sectional properties

Sheet Pile	H shape ($H \times B \times t_w \times t_f$) (mm)	Sectional properties (per 1 m length)		
		Weight (kg/m)	Moment of inertia (cm⁴/m)	Section modulus (cm³/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

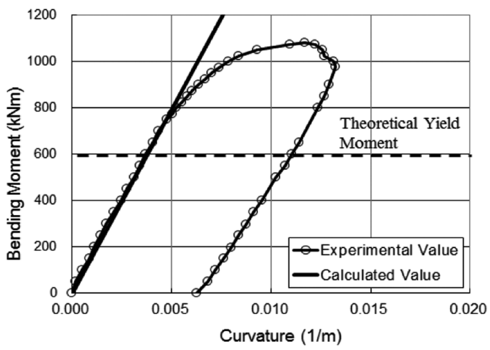


Fig. 3 Bending moment to curvature

Photo 2 Fabrication on site

chinery like that used in the vibratory hammer construction method and the impact hammer construction method (**Photo 3**, **Photo 4**). Furthermore, construction can be executed with high construction speed and high accuracies owing to the high rigidity of the Hat + H pile.

(2) Test for repeated pile driving

A test of repeated pile driving of Hat + H piles by vibratory hammer machinery was conducted in Singapore. The cross-section of the pile used is shown in **Fig. 4** and the soil condition is shown in **Fig. 5**. Three sets of the pile (H-shape steel: 24 m in length, Hat-type pile: 23 m in length) were used for the test and the driving and pulling-out work in the state of joints being interlocked was repeated six times. As shown in **Fig. 6**, six times repetitive driving and pulling out had no significant influence on the driving time. As shown in **Fig. 7**, the sweep of the pile which exerts influence upon the drivability is within the JIS specification (25 mm). Furthermore, as shown in **Fig. 8**, although deformation at the opening of the joint is observed, the deformation developed only in the near end portions of the pile and it was confirmed that the pile joints have sufficient durability against repeated driving.

2.5 Comparison with other construction methods (Based on example of application to temporary construction)

The soldier pile construction method has been used for large-scale earth retaining construction in South East Asia up to the present day. In the soldier pile method, H-shape steel and U-type steel sheet piles are driven in a separate manner and used for earth retaining. The soil pressure is transferred to the H-shape steel via the sheet pile. Since the sheet pile and the H-shape steel are driven separately, sometimes, reliability and safety become matters of concern due to the problem of construction accuracy. A comparison of the Hat + H piles and the soldier piles is shown in **Table 3**, where the cross-sectional performance (Z, I) is made equal. In Hat + H piles, since the steel sheet pile and the H-shape steel are combined by welding, effective sectional performance is enabled. As compared with the soldier pile, the section of which is assessed as a double row wall, weight reduction by 25–50% is realized, enabling the construction of a highly economical earth retaining structure.

2.6 Application to actual project

(1) Application to the permanent river revetment of the Pasig-Marikina River in the Philippines as countermeasures against flooding

This construction is a revetment repair construction for controlling the flooding damage of the Pasig-Marikina River that flows through the Manila metropolitan area and for improving the environments along the river. The project was executed by STEP-type Japanese ODA Loans. The construction site is in a densely populated urban area of Manila City and the construction work in a confined space was required. Nippon Steel & Sumitomo Metal conducted an on-site trial fabrication and driving tests of Hat + H pile and it was decided that the piles would be employed after verifying their applicability. The construction work was started in 2010 and completed in 2013 (**Photo 5**).

(2) Application to the temporary earth retaining wall for the construction work of Gardens by the Bay Station building of the Singapore Subway Thomson-East Coast Line

This project involves the construction work of Gardens by the Bay Station building of the Singapore Subway Thomson-East Coast Line ordered by the Land Transport Authority of Singapore. Hat + H piles were applied to the temporary earth retaining wall of the sta-

Photo 3 Installation by vibratory hammer

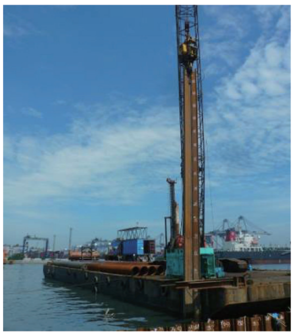


Photo 4 Installation by impact hammer

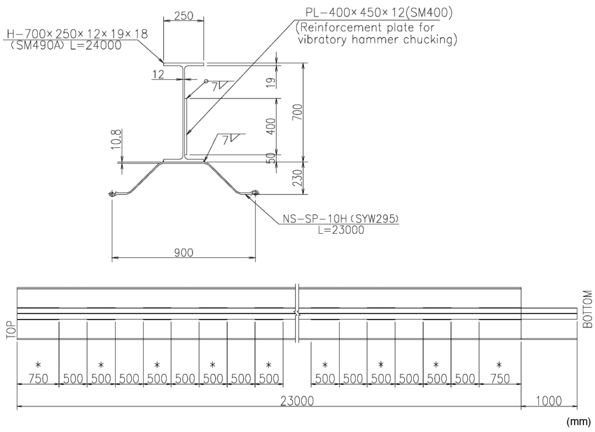


Fig. 4 Specimen of the pile

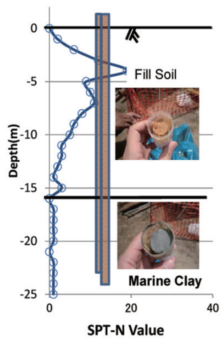


Fig. 5 Soil condition

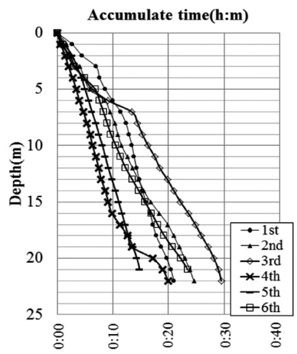


Fig. 6 Driving time

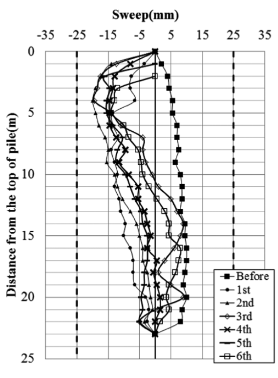


Fig. 7 Sweep of the sheet pile

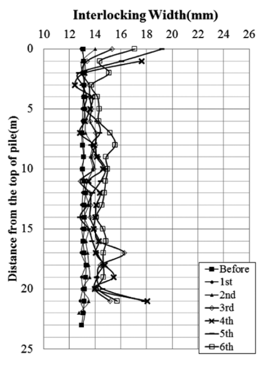


Fig. 8 Interlocking width

Table 3 Comparison study with the soldier pile system

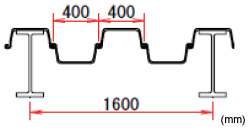
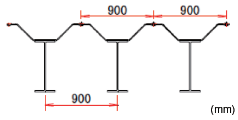
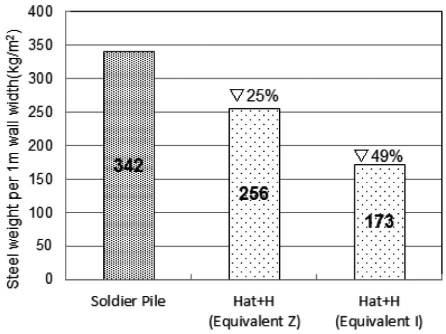
Type	Soldier pile Built-up section	Hat+H Composite section
Outline		
Section	H-shape: UB610×229×243 (mm) U-type steel sheet pile FSP-IV Section modulus Z=6264cm³/m Moment of inertia I=168000cm⁴/m	Equivalent Z=6770cm³/m 10H+HY750×250×12×19 (mm) Equivalent I=171000cm⁴/m 10H+HY700×250×12×19 (mm)
Comparison		

Photo 6 Installation of Hat+H at MRT Project in Singapore

Photo 7 Installed Hat+H at MRT Project in Singapore

Photo 5 Application to river revetment in Philippines (during construction)

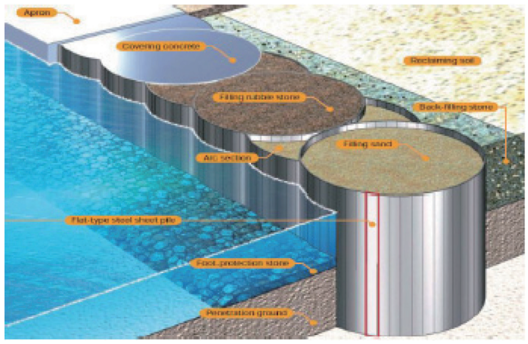


Fig. 9 Outline of steel sheet pile cell method

tion building construction. In the construction work, the Hat + H piles were employed owing to their highly appraised high rigidity, efficient cross-sectional performance, nearness of the fabrication work site to the construction site and excellent drivability (**Photo 6**, **Photo 7**).

2.7 Evolution in future

As described above, the Hat + H pile construction method is reliable from the structural viewpoint and furthermore, excellent in economy and drivability; the repeated use of piles for temporary earth retaining is possible. Furthermore, actual overseas experience has been steadily accumulated and Nippon Steel & Sumitomo Metal will push forward the overseas application of the pile with high rigidity to revetment, quay walls and large-scale temporary earth retaining construction.

3. Flat Steel Sheet Pile Cell Construction Method

3.1 Flat steel sheet pile cell construction method suited to revetment of reclaimed land and quay walls

The production of the flat steel sheet piles used for the steel sheet pile cell construction method was started in 1953 in this country and the sheet piles have been applied to a number of harbor and port facilities and artificial island construction projects such as the Kisarazu artificial island of the Tokyo Bay highway. The steel sheet pile cell construction method is used, as shown in **Fig. 9**, to construct a structure that consists of cylindrically assembled flat steel sheet piles and filled in with sand to withstand external forces. The steel sheet pile cell structure has the following features: high construction speed, possible penetration to ground and reduced ground improvement thereby, high stability in construction work after the completion of filling in with sand, reduced amount of steel and high economic efficiency and the applicability to the revetment of reclaimed land and quay walls is high. The flat type steel sheet piles of NSSMC have the following features:

1) High interlocking tensile strength of joints: 5.88MN/m or higher of NS-SP-FXL
2) High freedom of angular movement of joints in interlocking state: 10 degrees or higher

3) The maximum length of the product: 38 m

With these features, the applicable water depth of the cell structure is increased and workability is enhanced.

3.2 Application to revetment of artificial island of Hong Kong Hong Kong/Zhuhai/Macau Long Bridge

This project is a part of the large construction project of a highway of about 40 km connecting Hong Kong and Macau, and involves construction of a Hong Kong artificial island on the east side of Hong Kong International Airport planned for the installation of Hong Kong Boundary Crossing Facilities on the Hong Kong side territory (HKBCF). In the project, the steel sheet pile cell construction method was finally employed based on the following grounds that the construction method is: 1) environment-friendly and appropriate for a construction site inhabited by an endangered animal (white dolphin), 2) able to solve the aeronautical height limitation and, 3) highly appreciated for the integrated system of NSSMC in manufacturing, designing, execution of construction and delivery, verified by numerous domestic and overseas project experiences.

1) For the protection of the endangered animal, the impact hammer construction method and the use of a water jet are prohibited, but the steel sheet pile cell construction method can be executed by vibratory hammer machinery alone.
2) This construction site is adjacent to Hong Kong International Airport and the aeronautical height limitation has to be strictly observed even during the construction period. To comply with the limitation, installation barges for exclusive use were built (**Photo 8**).
3) In the construction, 85 steel sheet pile cells 26.9 m and 31.194 m in diameter with a length of 23.6 m–37.1 m were used. A semi-prefabrication method was employed in which a quarter of a cell was fabricated on land, transported to the site by a barge of exclusive use and fabricated to a complete cell on-site (**Photo 9**). The construction of the steel pipe pile cell was started in 2012 and the construction of the steel sheet pile cells was completed in 2014 (**Photo 10**).

Henceforth based on this result, Nippon Steel & Sumitomo Metal is determined to further promote the application of the construction method to the revetment of large-scale reclamation constructions for airports, industrial waste disposal sites, highways and so forth not only in Hong Kong, but also in other overseas countries.

Photo 8 Installation barges for limited height for construction

Photo 9 Delivery the fabricated quarter cells

Photo 10 Installation of steel sheet pile cell at HKCBF in Hong Kong

4. Sat-in Pile Foundation

4.1 Steel pipe pile foundation construction method to realize on-site labor reduction

Encouraged by the brisk investment in resources and energy, exploration of such is spreading worldwide. In a company with such movements, exploration in remote areas where active developments have not been conducted so far and the construction of nearby related land plants are in progress. In these areas, arrangements of site workers are difficult and although the situation depends on countries, there are problems of harsh climates, safety, escalating labor cost and stringent environmental regulations and therefore the need for on-site labor reduction is high.

As shown in **Fig. 10**, the Sat-in pile foundation is the one-column in one-pile system in which the column of the upper structure is directly inserted into the inside of a relatively large pipe pile and connected thereto. It is a foundation type developed for iron and steel plants as one of the methods for labor-saving in foundation construction and shortening of the construction period. Domestically, the certification by the Building Center of Japan (a general incorporated foundation) was obtained in 2003 (No. BCJ Rating-FD0061-01)[3] and the actual application results of more than 20 mainly plant foundations have been achieved. When compared with

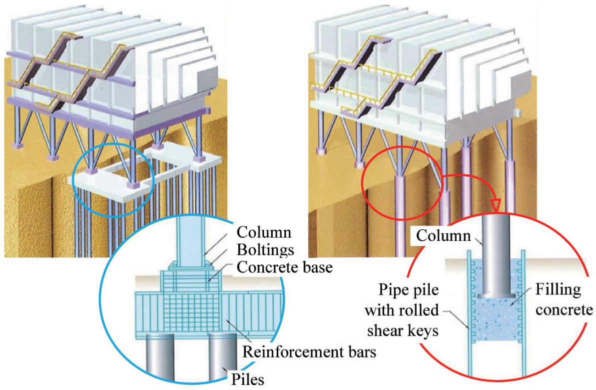


Fig. 10 Sat-in pile foundation

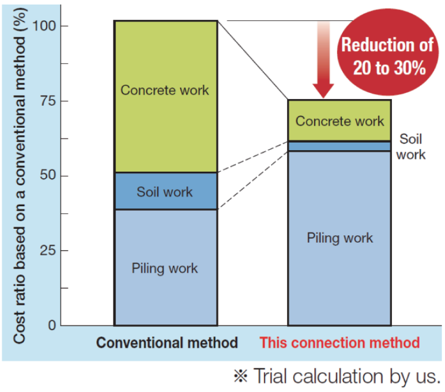


Fig. 11 Estimation of cost reduction

the conventional concrete footing foundation, reduction in the amounts of earthwork and concrete work, both of which are labor incentive work, is possible and as shown in **Fig. 11**, the total cost of the foundation work can be reduced by about 20–30% and shortening of the construction period by about 30–40% is possible. Furthermore, as compared with the concrete footing foundation, the area occupancy ratio is low and the freedom of work of land-buried piping and wiring that is indispensable to plant construction can also be enhanced.

4.2 Outline of structure of Sat-in pile foundation and load transfer

The Sat-in pile foundation is a joining method of a column and a foundation steel pipe pile in which the inside of the steel pipe pile is filled in with concrete after the column is inserted into the steel pipe pile through its head. For the pipe pile, internally ribbed pipe piles (projection) (JIS A 5525)[4] are used in order to secure the transfer of the load from the upper structure via the filled-in concrete. As **Photo 11** shows, a rolled steel strip sheet with projections of a height of 2.5 mm or higher that are arranged at a spacing distance of 40 mm or less is formed on a pipe by the spiral pipe forming method so that the projections are formed spirally on the inside of the pipe. There are no restrictions on the installation method of the steel pipe pile and the method is applicable to the impact hammer driving method, inner excavation method, rotational pile penetration method and so forth.

Among the loads exerted by the upper structure, the axial load is transferred to the lower filled-in concrete as the bearing pressure of the base plate installed at the bottom of the inner column and the filled-in concrete supports the bearing pressure, being supported by the internal projections of the outer steel pipe. On the other hand, the acting bending moment and the horizontal shearing load are transferred to the upper filled-in concrete as a form of bearing pressure of mainly the side surface of the column and to the outer steel pipe, where it is transformed to a hoop tension and supported (**Fig. 12**).

4.3 Application of Sat-in pile foundation to foundation of overseas plant

(1) Problem in application

Although the Sat-in pile foundation is a construction method that has already obtained the certification of the Building Center of Japan and has actual records of application, for the application to the foundations of overseas land plants, the following problems exist.

1) Design method: Application to limit state design method (LRFD)
2) Structural scale: Application to piles 1200 mm or larger in diameter

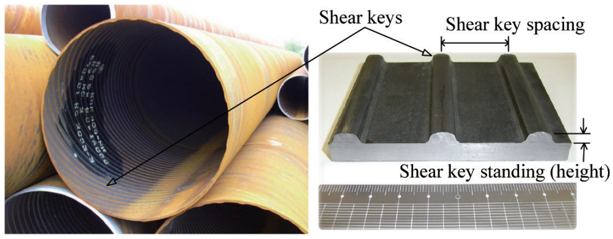


Photo 11 Steel pipe with ribs and the detail

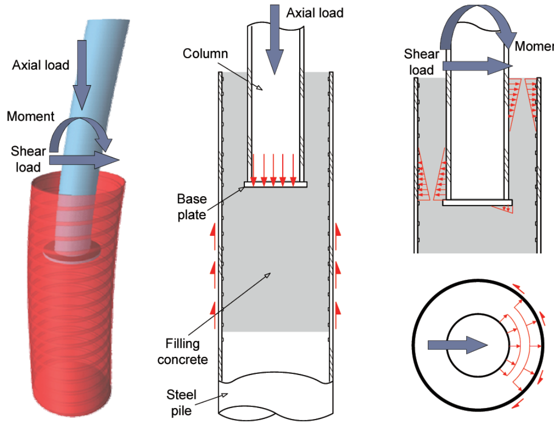


Fig. 12 Load transfer in Sat-in pile foundation

3) Certification: Acquisition of international certification issued by an overseas third party organization

Then, in order to obtain the technical qualification[5,6] of the structure and design method of DNV (Det Norske Veritas; Current DNV-GL), an organization rich in actual results of granting technical qualifications in design standard and approval of projects of a number of jacket foundations and monopile type foundation structures of the latest offshore wind turbines, a study on the respective technical problems to solve the abovementioned issues was executed.

Domestically, since the design method based on the allowable stress has already been established, the transition to the limit state design method is achieved by rearranging the possible fracture mode and by transferring it to the formulae that conforms to the limit state design method.

Among the technical problems, correspondence to the pipe pile 1 200 mm or larger in diameter was required to expand the area of application (structure scale). Particularly, the assessment of the bond strength of the steel pipe with internal projections that governs the transfer of the axial load is important. In the domestic assessment, the adhesion strength of the steel pipe with internal projections is determined by whichever is smaller of the calculated values of the strength of the projection against the bearing pressure or the sharing strength of the concrete generated between the two adjacent projections but, the specification of the steel pipe such as diameter and wall thickness is not taken into consideration when calculating the strength. However, the internal adhesion property of the projected steel pipe is dependent on the restraining effect of a steel pipe[7] and is strongly affected by mainly the diameter vs. wall thickness ratio of the steel pipe. Accordingly, it is difficult to apply the conventional adhesion strength calculation method to expanded steel pipe piles and review of the calculation method was required.

(2) Revision of assessment method of adhesion property [8)]

Upon revising the adhesion property, collection and analysis of the already existing data used for applications for assessment were conducted and an additional test was performed. The data thus obtained cover almost the entire area of practical construction of a diameter vs. wall thickness ratio of 38–67 (D/t; D is the pile diameter, t is the wall thickness.), concrete strength (F_{cu}) of 25–50 N/mm^2 and a shear key ratio of 0.06–0.12 (h/s; h is the projection height, s is the projection spacing).

Figure 13 shows the result of the push-out test conducted for the assessment of the adhesion strength (F_{bu}) of an internally projected steel pile. The result indicates that the adhesion strength (F_{bu}) can be very precisely assessed by taking into consideration the diameter vs. wall thickness ratio in addition to the shape of the projection. As a result of the technical discussion with DNV, the following assessment method was employed ultimately by referring to the computation formula of shear-key type grout joining in the monopile foundation of offshore wind turbine structures. [9)] A comparison of the experimental result and the assessment formula result is shown in **Fig. 14**. It is confirmed that the adhesion strength can be very precisely assessed on the conservative side.

$$F_{bu} = \left[2 \left(\frac{400}{D} \right) + 140 \left(\frac{h}{s} \right)^{0.8} \right] \left(\frac{D}{t} \right)^{-0.6} F_{cu}^{\ 0.3} \qquad (1)$$

For the application of the Sat-in pile foundation to overseas plant foundation, the aforementioned transition to the limit state design method and the review of the adhesion strength of the internally projected steel pipe were executed. These studies were conducted under repeated consultation with DNV, and the examination of the feasibility of the structure and the proposal of the structure designing method have already been completed. Although maintenance of the construction and quality control regulations remains to be conducted, which is scheduled to be completed at the final stage, confirmation of the structural stability and the designing method have been completed and application to actual structural constructions is possible.

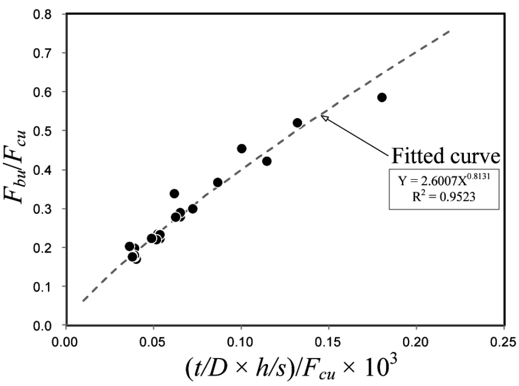


Fig. 13 Analysis on the datasets from push-out tests

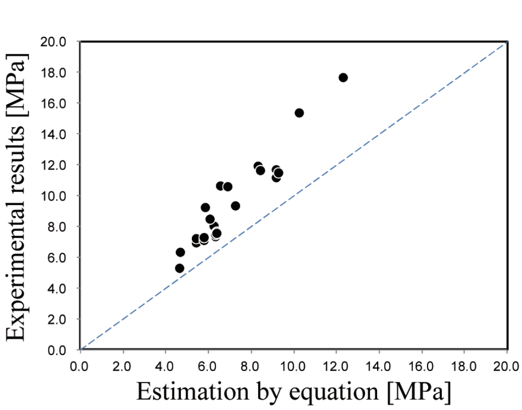


Fig. 14 Experimental data against estimation

4.4 Acquisition of international certification and future evolution

There are a number of domestic records of the Sat-in pile foundation and based on the technical study introduced in the article, large quantities of internally projected steel pipe pile were employed in the Ichthys LNG Project now under construction off Darwin in Australia operated by INPEX CORPORATION. They are greatly contributing to the establishment of non-soil removable construction and man-power saving for foundation construction at the site. With the actual records and the acquisition of the international certification, Nippon Steel & Sumitomo Metal is determined to push forward the application of the method to the joining method of large-scale module structures in the energy facility construction in remote areas.

5. Conclusion

This article describes the approach and the actual results of the development achieved so far in the overseas market of high-end products of the major civil engineering and building materials of steel sheet piles and steel pipe piles. In order to develop the overseas market, the product and the construction method must be advantageous specifically to respective countries and competitive to competing products. Henceforward, Nippon Steel & Sumitomo Metal is determined to continue to exploit the demand in overseas civil engineering and building materials by developing the products and construction method suited to the overseas market based on the technologies of Nippon Steel & Sumitomo Metal developed so far in Japan (rapid execution of construction work, construction work in confined space, labor saving and so forth) and by further improving the existing products and the construction method.

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