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Development of Hat-Type Sheet Pile 900

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Abstract

Hat-Type Sheet Pile 900 was developed as a new generation sheet pile with improved drivability, higher structural reliability, and more economical merit compared with traditional U type sheet piles. Hat-Type Sheet Pile 900 which has thin and large section shape of 900mm in effective width has been developed on the basis of state-of- the-art rolling technology and design/construction know-how, and has been commercially available since 2005. In this report, the feature of Hat-Type Sheet Pile 900 is revealed. Also, drivability/structural performance test results are shown, and finally some application examples are introduced.

1. Introduction

In Japan, steel sheet piles have been used extensively in work for rivers, ports, and as temporary earth retaining, etc. since first being domestically manufactured in the 1930s. The Hat-Type Sheet Pile 900 described in this paper is a steel sheet pile developed jointly by Nippon Steel, JFE Steel and Sumitomo Metal Industries. It has good drivability, offers excellent structural stability and helps cut construction costs.

As shown in **Fig. 1** and **Photo 1**, Hat-Type Sheet Pile 900 is a hat-shaped steel sheet pile with an effective width of 900 mm. At present, as a solid rolled steel product, it is the world's widest sheet pile. This sheet pile is available in two types of sections—10H and 25H. It has sectional properties as shown in **Table 1**.

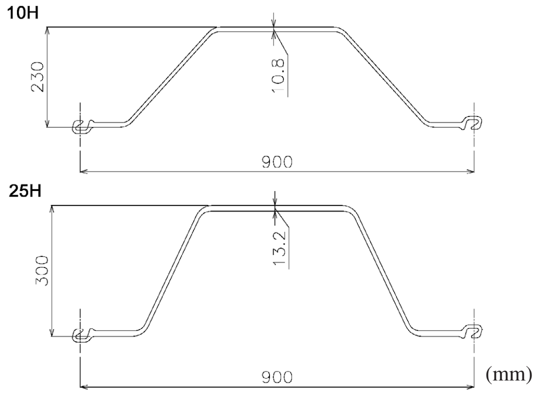

Fig. 1 Profile of Hat-Type Sheet Pile 900

2. History of Steel Sheet Pile Development

Steel sheet piles are reported to have been used for the first time in Japan for the earth retaining wall during construction of the Mitsui Head Office from 1903[1]. After that, large quantities of steel sheet piles were imported from around the world for post-disaster construction and damage repair in the wake of the Great Kanto Earthquake of 1923. The speedy disaster-relief work of the ports and rivers that had been badly damaged by the earthquake was considered attributable largely to the steel sheet pile method. In the early Showa era, tens of thousands of steel sheet piles were imported annually.

In 1929, the former government-managed Yawata Works began domestic production of steel sheet piles. It started manufacturing and selling domestic steel sheet piles in 1931. After that, imports of steel

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Table 1 Sectional properties of Hat-Type Sheet Pile 900

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
10H	900	230	10.8	122.2	10,500	902	96.0
25H	900	300	13.2	160.4	24,400	1,610	126

Photo 1 Hat Type Sheet Pile 900

sheet piles decreased and domestically produced steel sheet piles predominated. Thanks to the subsequent development of rolling technology that permits mass production of steel sheet piles and new application techniques for efficient execution of both design and pile driving, together with rapid economic growth, the annual demand for steel sheet piles exceeded one million tons during the 1970s and 1980s. With the attainment of an appreciably high level of social infrastructure in recent years, demand for steel sheet piles has remained at around 600,000 tons per annum.

About 80 years have passed since the former government-managed Yawata Works started domestic production of steel sheet piles. In the meantime, U-type sheet piles with an effective width of 400 mm have mainly been used. In 1997, due to economic woes and the like, the Ministry of Construction formulated an “Action Plan for addressing cost reduction of public works”[2]. Since then, reducing the construction costs has been a social necessity. Nippon Steel developed a “Wide Type Steel Sheet Pile”—a U-type steel sheet pile with an effective width of 600 mm, and started manufacturing and sales in 1997. As a result, the Wide Type Steel Sheet Pile replaced the U-type steel sheet pile (effective width: 400 mm) for wall stractures in permanent structures, mainly those in river and port projects. However, it became necessary to further cut construction costs and develop new uses for steel sheet piles. Under such conditions, Nippon Steel improved its accumulated technology and know-how relating to rolling and pile driving, and pressed ahead with the development of a new-generation steel sheet pile, that is, the Hat-Type Sheet Pile 900. Nippon Steel began manufacturing and selling this new type of sheet pile in 2005.

3. Development of Hat-Type Sheet Pile 900

3.1 Shape and features of Hat-Type Sheet Pile 900

The Hat-Type Sheet Pile 900 has a hat-shaped cross section, is relatively thin, with a large sectional area. This permits efficient implementation of pile-driving work, securing high structural reliability and achieving significant economies.

<Efficient pile-driving work>

Since the Hat-Type Sheet Pile 900 is more rigid than conventional Wide Type Sheet 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 as shown in **Fig. 2**, the neutral axis of each of the piles coincides with that of the wall structure formed. Therefore, the “joint efficiency” (i.e., the decline in sectional performance ascribable to the sheet pile

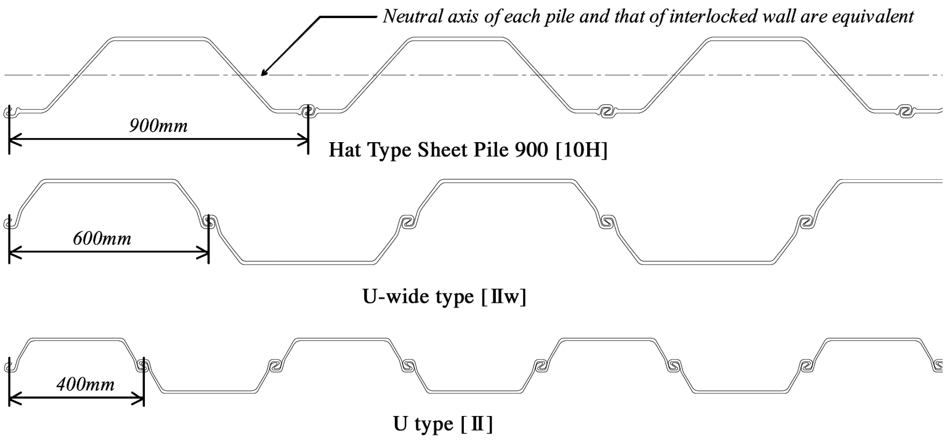


Fig. 2 Comparison of Hat-Type Sheet Pile 900 and U type sheet pile

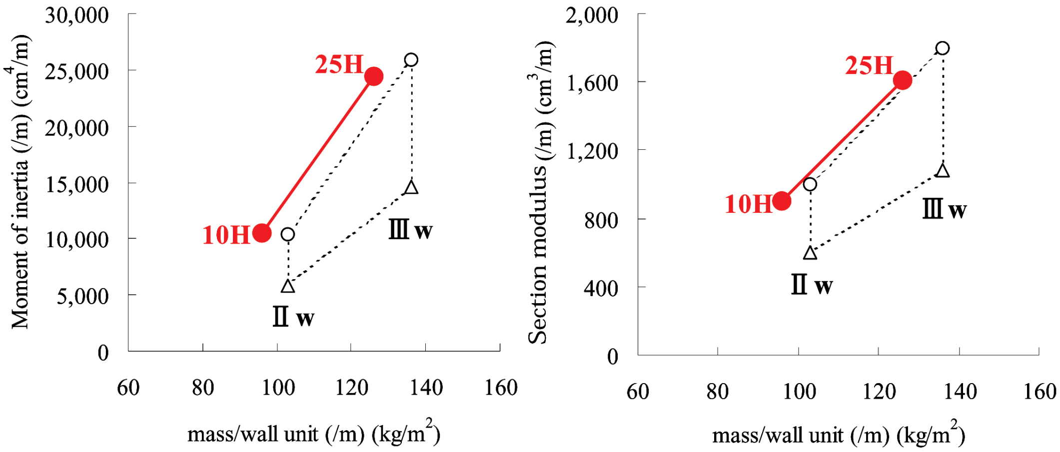


Fig. 3 Relationship between steel weight and sectional performance

shape and joint position) that needs to be considered when the U-type sheet pile is used may be left out of consideration. Thus, Hat-Type Sheet Pile 900 is able to display its structural performance under various construction conditions.

<Improved economies>

As shown in **Fig. 3**, the Hat-Type Sheet Pile 900 enables a reduction in the amount of steel required per unit wall area. It also enables a reduction in the number of sheet piles used, making it possible to shorten the construction period and cut construction costs. In addition, the new sheet pile allows for efficient structural design in which the joint efficiency need not be taken into consideration.

3.2 Pile-driving test

3.2.1 Development of pile-driving methods

The vibratory driving or the hydraulic jacking methods are commonly used to drive steel sheet piles into the ground.

In the vibratory driving (**Photo 2**) method, as the hammer vibrates while chucking the top of the sheet pile, the vibration is transmitted to the sheet pile and ground, so that the sheet pile is driven into the ground. This method is the most popular because it can shorten the construction time and can be applied even to hard ground.

In the hydraulic jacking method (**Photo 3**), resistance to withdrawal of a sheet pile which has already been driven into the ground is used as the reaction to push another sheet pile statically into the ground. This method is suitable for low-vibration, low-noise pile-driving at construction sites in urban areas and for pile-driving at confined construction sites.

Concerning both the vibratory driving and hydraulic jacking method, the machines used for Hat-Type Sheet Pile 900 have been improved.

For the machine used in the vibratory driving, a mechanism which chucks the sheet pile at two points (double chucking mechanism) as shown in **Fig. 4** has been developed as the standard one in order to transmit the hammer's vibration efficiently to sheet piles with a large sectional area, whereas a single chucking mechanism is used for conventional U-type sheet piles. The vibro-hammer itself does not need any modification. It can be applied to Hat-Type Sheet Pile 900 simply by installing the double chucking device to its sheet pile holding mechanism.

In the hydraulic jacking method, a machine exclusively for Hat-Type Sheet Pile 900 as shown in **Fig. 5** is used. This machine also chucks the sheet pile at two points so as to transmit the pressure efficiently to sheet piles with a large sectional area, whereas the

Photo 2 Driven Hat-Type Sheet Pile 900 by vibratory driving

Photo 3 Driven Hat-Type Sheet Pile 900 by hydraulic jacking method

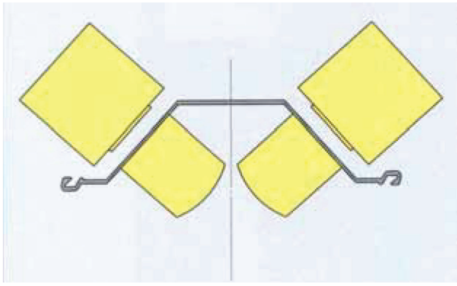


Fig. 4 Jacking method of vibratory driving for Hat-Type Sheet Pile 900

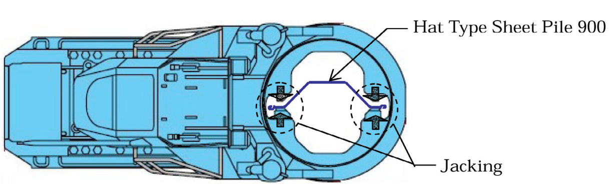


Fig. 5 Hydraulic jacking machine for Hat-Type Sheet Pile 900

machine used on conventional U-type sheet piles chucks at a single point.

3.2.2 Testing to confirm driving performance with vibro-hammer method

Of the field tests carried out to confirm the performance of the vibro-hammer method in putting Hat-Type Sheet Pile 900 into practical use[3], the test conducted on the grounds of Nippon Steel Technical Center in Futtsu City, Chiba Prefecture shall be described below.

In the test, a comparison of the pile-driving performance was made between Hat-Type Sheet Pile 900 (10H, 12 m long) and U-wide-type sheet pile (IIw, 12 m long). The vibro-hammer used was a hydraulic, ultrahigh-frequency type (SR-45). The sheet piles were driven into the ground using the vibro-hammer method, without auxiliary means, such as water jet, being used. To chuck the sheet piles, a double chucking device was used for Hat-Type Sheet Pile 900 and single chucking device was used for the U-wide-type sheet pile.

Fig. 6 shows the soil profile at the test site, the driving time for each meter depth and the change in hydraulic pressure of the vibro-hammer. The ground is mostly sandy with an N-value of around 10. From a depth of about 11 m, the N-value increases to 30 or more. The U-wide-type sheet pile shows a slightly shorter driving time. However, considering that the Hat-Type Sheet Pile 900 has a sectional area and periphery length 1.4 times greater than the U-wide-type sheet pile, and that there is little difference in the vibro-hammer hydraulic pressure between them, it may be said that the Hat-Type Sheet Pile 900 has good driving performance.

3.2.3 Testing to confirm driving performance with hydraulic jacking method

In this section, the test conducted within the Kochi No. 2 plant of Giken Seisakusho Co., Ltd. in Kochi City is described. In the test, a Hat-Type Sheet Pile 900 (10H, 15 m long) and U-wide-type sheet pile (IIw, 15 m long) were used. The sheet piles were driven into the ground using the hydraulic jacking method. No auxiliary means, such as water jet, were used.

Fig. 7 shows the soil profile at the test site, the driving time for each meter depth and the change in driving load. The ground consists of alternate layers of sandy soil and clayey soil having an N-value of around 10. In the test, the sheet piles were driven into the ground not only in a straight alignment but also in a curved alignment (**Photo 4**). The joint fitting angle in the curved alignment was 4 degrees—the maximum value of the standard rotation angle of the Hat-Type Sheet Pile 900 for pile driving.

Due, at least in part, to a relatively uniform soil profile at the test site, both Hat-Type Sheet Pile 900 and the U-wide-type sheet pile could be driven into the ground at an almost constant speed. Hat-Type Sheet Pile 900 required a slightly longer driving time and a slightly larger driving force. Considering that the Hat-Type Sheet Pile 900 has a larger sectional area, however, it may be said that it has good driving performance.

3.3 Bending test

In order to evaluate the bending resistance characteristic of the Hat-Type Sheet Pile 900, 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 **Fig. 8**. The vertical axis in Fig. 8 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 was confirmed from the bending test that just as with the Hat-Type Sheet Pile 900, the “joint efficiency” can be omitted from consideration.

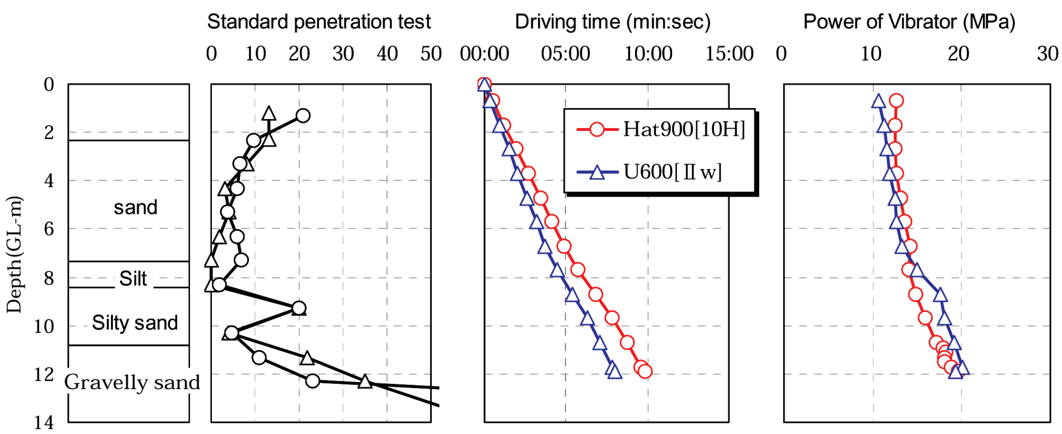


Fig. 6 Field test result by vibratory driving

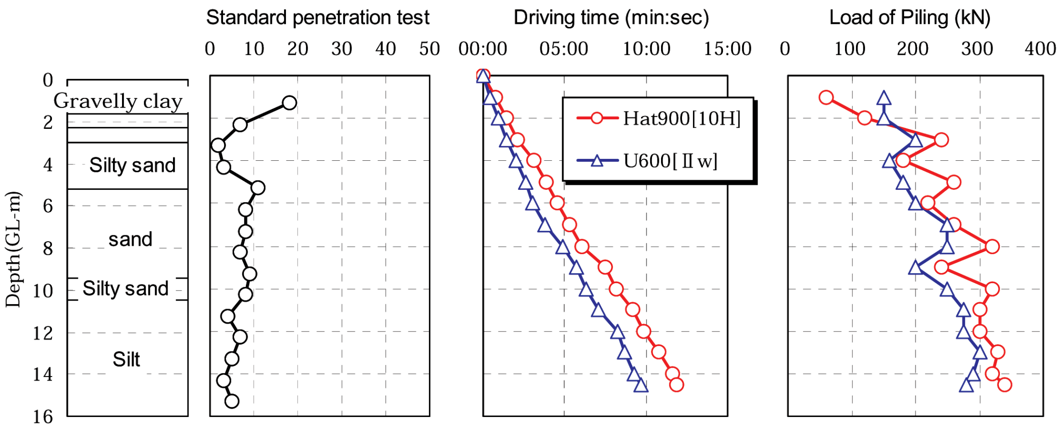


Fig. 7 Field test result by hydraulic jacking method

Photo 4 Curved alignment

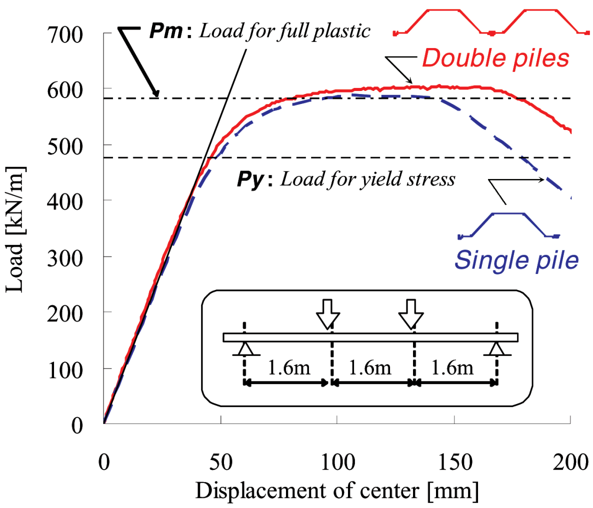


Fig. 8 Result of four-point bending tests

3.4 Testing to confirm watertightness

The waterproof performance of the Hat-Type Sheet Pile 900 was tested on untreated joints and after the joints had waterproof material applied[3]. Here, the results of the watertightening test with the joints untreated are described. In the test, the Hat-Type Sheet Pile 900 (10H) and U-wide-type sheet pile (IIw) were used. First, as shown in **Fig. 9**, 10H piles and IIw piles were driven into the ground in the form of a rectangle alignment using the hydraulic jacking method. Then, the ground was excavated to a depth of 2.5 m and the state of water leakage from the joints was observed. Since the degree of water leakage from sheet pile joints varies according to the properties of the surrounding soil (permeability, grain size distribution, etc.), the head of groundwater, the fit condition of the joints, etc., it is difficult to quantitatively evaluate the waterproofing performance of the Hat-Type Sheet Pile 900 definitely with this test alone. However, in the relative comparison of the two types of sheet piles made in the test, they showed no significant difference in the condition of water leakage as shown in **Fig. 10**. Therefore, it is considered that they have nearly the same degree of watertightness.

3.5 Tensile test of joints

In order to confirm the joint tensile strength of the Hat-Type Sheet Pile 900, 100-mm long test pieces were subjected to a tensile test. Using a displacement gauge and a gauge length of 100 mm, the test load was increased to the point at which the steel ruptured or the joints separated[3]. The average maximum load for three test pieces was 62.6 kN for 10H and 72.6 kN for 25H. In every case, the joints opened and came off. In tensile tests of U-wide-type sheet piles carried out in the past, the maximum load was about 50 kN. Thus, it was confirmed that the Hat-Type Sheet Pile 900 is comparable in joint strength to the U-wide-type sheet pile.

4. Application of Hat-Type Sheet Pile 900 in Actual Projects

The Hat-Type Sheet Pile 900, first manufactured and marketed in 2005, was initially employed largely in pilot projects controlled by the Ministry of Land, Infrastructure and Transport. At actual construction sites, the sheet pile proved to be effective in cutting the construction costs and shortening construction periods. Based on this success, use of the Hat-Type Sheet Pile 900 increased sharply in fiscal 2006[3]. In the early stages of application of the Hat-Type Sheet Pile 900, it was tested and reviewed at the construction sites. Several application examples are outlined below.

[Example 1][4]

Sheet pile used: 10H, 6.5 m in length

Constructed: 2005

Pile-driving method: Vibratory driving (hydraulic, variable, ultrahigh-frequency type)

Results: Hat-Type Sheet Pile 900 enabled a reduction in the total weight of the steel material compared to conventional U-wide-type sheet piles and cut material costs.

[Example 2][5]

Sheet pile used: 10H, 11 m in length

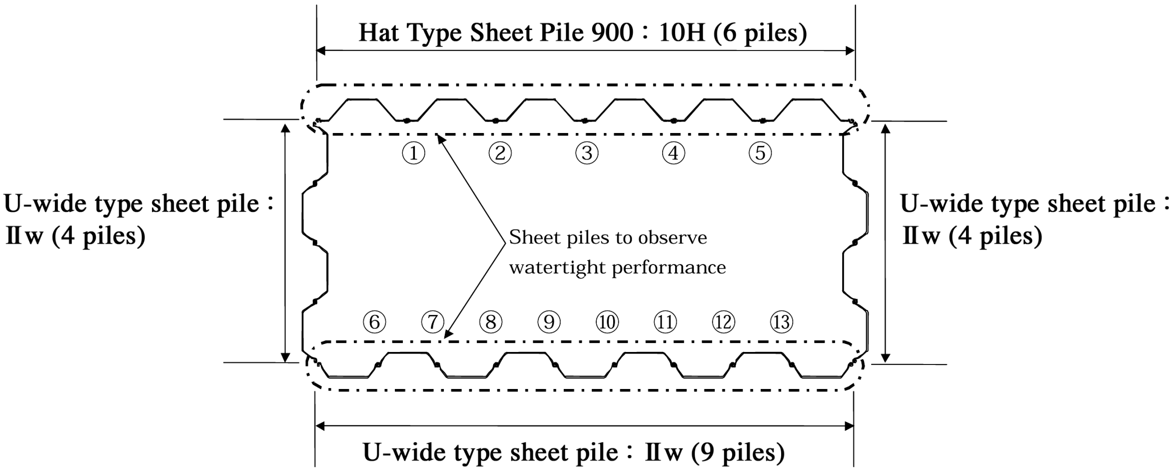


Fig. 9 Sheet pile arrangement of field test to observe watertight performance

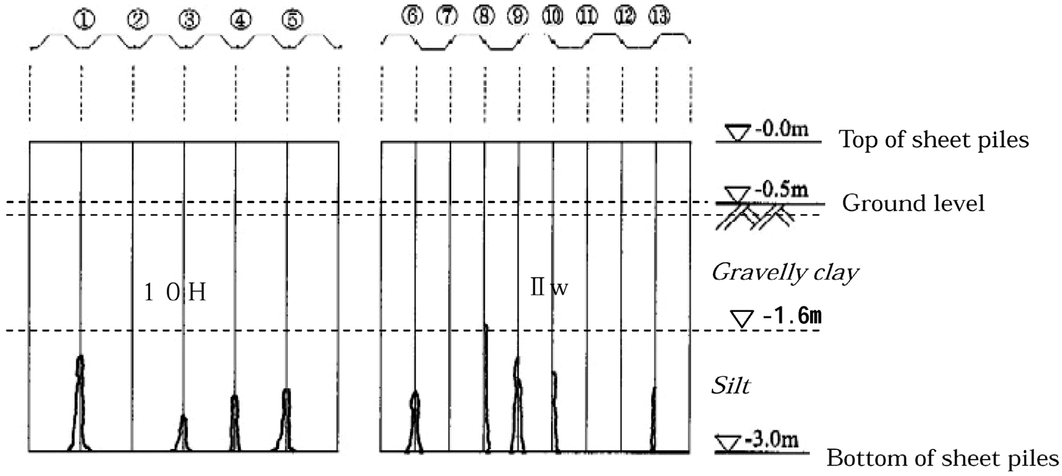


Fig. 10 Groundwater leakage (without treatment for the interlocking section of sheet piles)

Pile-driving method: Vibratory driving (hydraulic, variable, ultrahigh-frequency type)
Constructed: 2005
Results: Because application of the Hat-Type Sheet Pile was still not very popular, pilot operations using the Hat-Type Sheet Pile 900 (10H/25H) and U-wide-type sheet piles (IIw/IIIw) were carried out prior to the actual construction work to measure construction time, vibration, noise, etc. Based on the results of the pilot operations, 10H was adopted for the actual construction work (total length: 450 m). It was confirmed that 10H helped to cut the material and construction costs and shorten the construction work period.

[Example 3][6)]
Sheet pile used: 10H, 9.5 m in length
Pile driving method: Vibratory driving (hydraulic, variable, ultrahigh-frequency type)
Constructed: 2005
Results: Hat-Type Sheet Pile 900 proved to be more economical than the conventional U-wide-type sheet pile in terms of the costs of materials, etc., although it did not significantly shorten the construction period. This project was in Shikoku, and was the first to apply Hat-Type Sheet Pile 900. Once this sheet pile becomes more widespread, there is a possibility that it will help shorten construction periods and cut construction costs further.

[Example 4][7)]
Sheet pile used: 10H, 11 m in length
Pile-driving method: Vibratory driving (hydraulic, variable, ultrahigh-frequency type)
Constructed: 2005
Results: Because the Hat-Type Sheet Pile 900 enabled a reduction in the number of sheet piles to be driven into the ground, construction costs could be cut.

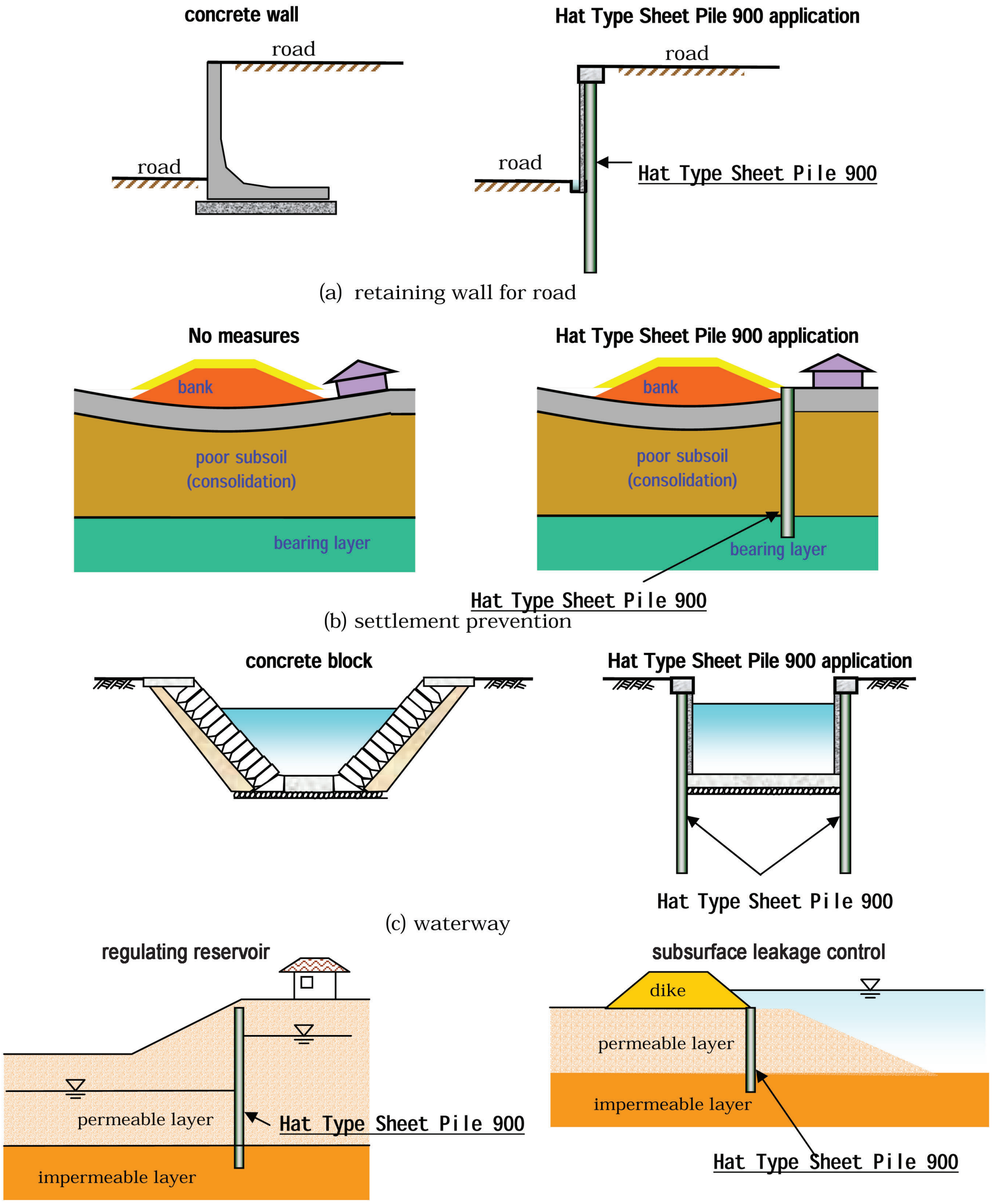
The examples given above are from the period when the application of Hat-Type Sheet Pile 900 just began and there were few suitable pile-drivers. As more and more construction projects are using this type of sheet pile, efficient pile-drivers are increasing in number. The use of a vibro-hammer to drive in the Hat-Type Sheet Pile 900 was included in the “Standards for Estimating Costs of Civil Engineering Works, 2007” published by the Ministry of Land, Infrastructure and Transport[8)]. With the shift from being a new method to the standard method, it will become more widespread in the future.

5. Conclusion

The Hat-Type Sheet Pile 900 is a structural steel product that incorporates the essence of sheet pile manufacturing technology and application technology relating to design and construction work. Its application extends beyond conventional civil engineering works, such as river revetments and port piers. As shown in **Fig. 11**, it can also be applied to road retaining walls and stress insulating walls, waterway walls, watertightening walls, etc. as measures to prevent ground subsidence. By promoting the Hat-Type Sheet Pile 900, we hope to contribute much to cutting construction costs and shortening construction periods.

Acknowledgments

We wish to express our heartfelt thanks to the persons concerned at Chowa Kogyo Co., Ltd. and Giken Seisakusyo Co., Ltd. for their generous cooperation in developing our pile-driving machinery and methods.



(d) various watertightening wall

Fig. 11 Application of Hat-Type Sheet Pile 900

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