Development of Mechanical Joint New "High-Mecha-Neji™" for Steel Pipe Piles and Steel Pipe Sheet Piles

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Abstract:

JFE Steel has developed a mechanical joint "High-Mecha-Neji™" for steel pipe piles as a temporary construction use for railroads in 1998, and acquired public approval for real constructions in the field of public works in 2011. To raise its competitiveness in the social environment where the need of the mechanical joint has increased, we have largely expanded the application range of the diameter, thickness, strength, and construction method of the pile, and reviewed the structure of the joint to improve workability. We have inspected the effect of the changes by structural experiments, analyses, and construction tests, and renewed the approval as new "High-Mecha-Neji". This paper introduces process and contents of the development.

1. Introduction

JFE Steel commercialized a threaded mechanical joint for steel pipe piles trade-named "High-Mecha-Neji™" as a product for temporary construction use for railroads from 1998, and increased its construction record by acquiring Construction Technology Review and Certification[1)] for the general civil engineering field in 2011.

On the other hand, variotious trends in the environment surrounding steel pipe piles are accelerating, including (1) Large-diameter, thick-walled, high-strength products, (2) Securing strength reliability, (3) Severe working conditions such as reduction of construction period, low overhead conditions, narrow working space, hard ground, etc., (4) Development of various construction methods and (5) Large decrease in skilled welders (now fewer than 200 000[2)]), heightening the necessity of mechanical joints.

Based on these conditions, JFE Steel conducted structural tests, analyses and construction tests and established a new joint specification in order to greatly expand the application range of "High-Mecha-Neji." Public certification was renewed, and the product was commercialized as new "High-Mecha-Neji."

This report describes the content of the above-mentioned study.

2. Outline of Development

2.1 Outline of Joint

The outline of the conventional type "High-Mecha-Neji" is presented below.

(1) Thread geometry: Insertion type joint with parallel and multi-start threads

Excellent workability is secured by insertion type parallel threads with extra length in the leading end of the thread, which enables easy positioning during jointing and thereby prevents jammed screws and other construction problems, together with adoption of a four start thread (four thread inlets points), which reduces the number of turns necessary for jointing to about 1 or 2 turns, even when using joints with a large number of threads for thick-walled steel pipes.

(2) Material and production method: High strength steel material

The joint material used in "High-Mecha-Neji" is JFE-HITEN780, an original JFE Steel standard

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that the yield point of 685 N/mm^2 or higher and tensile strength of 780 N/mm^2 or higher are secured.

After rolled ring forging and heat treatment of steel billets, joints are manufactured by automatic thread cutting. Since excessive joint thickness is avoided by using high strength steel, application to pile installation by inner excavation is also possible. Moreover, field welding is not necessary because joints are welded to steel pipes in the shop before shipment.

(3) Joint performance: Higher strength than pile

In the joint specification, the strength of the joint is higher than that of the steel pipe (including compressive, tensile, bending and shear strength). Between 3 and 5 joint specifications have been standardized for each pipe diameter for one-to-one correspondence with the plate thickness and strength. It is possible to transmit torsional torque corresponding to the number of pins by the shear resistance of the counter-rotation pins, which are installed spanning the pin joint and box joint after makeup is completed.

The structure of "High-Mecha-Neji" is shown in **Fig. 1**, and the construction site of "High-Mecha-Neji" is shown in **Photo 1**. Under normal conditions, the pin joint is frequently arranged on the upper pile side to facilitate alignment, but it is also possible to arrange the box joint on the upper pile side.

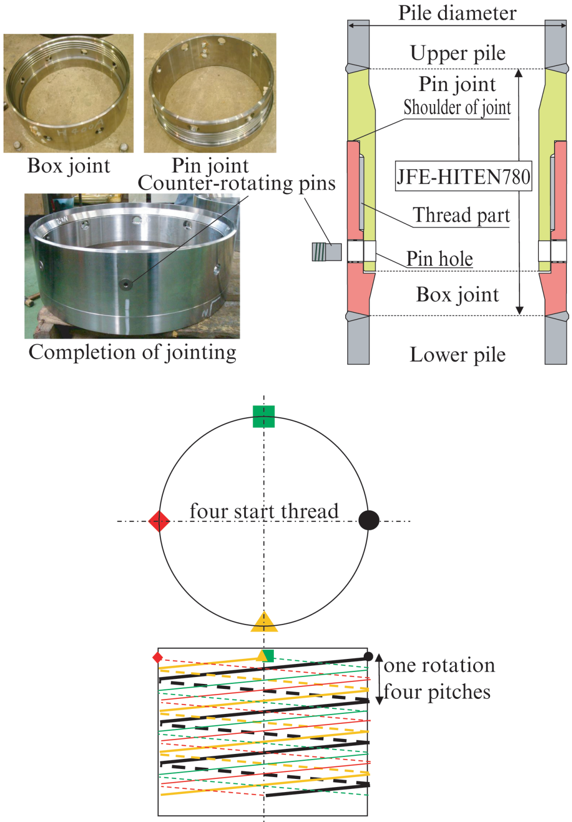

Fig. 1 Structure of "High-Mecha-Neji™"

Photo 1 Constructing of "High-Mecha-Neji™"

2.2 Design Concept of New "High-Mecha-Neji™"

While keeping the basic specification of "High-Mecha-Neji", its application range was expanded based on the following conditions. A comparison with the conventional type is shown in **Table 1**.

(1) The steel material of new "High-Mecha-Neji" supports high strength steel pipe piles up to SM570, and the joint specification supports the maximum diameter of 2 000 mm mentioned in Japan's Specifications for Highway Bridges[3]. In addition to these changes, the joint was also shortened.

(2) Workability was improved. The number of turns required for jointing was reduced (in the case of parallel threads, the number of turns equals number of threads / number of starts). The maximum number of starts is 16 and the maximum thread

Table 1 Comparison with conventional type

	Conventional type	New type
Pipe diameter	318.5 mm-1 200 mm	318.5 mm-2 000 mm
Pipe thickness	6 mm-35 mm (SKK400) 6 mm-28 mm (SKK490)	6 mm-60 mm (SKK400, SKY400) 6 mm-45 mm (SKK490, SKY490) 6 mm-30 mm (SM570, SM490Y)
Piling method	Bored pile Rotation pile Jacked pile	Bored pile Rotation pile Jacked pile Driven pile
Number of starts	4	4-16
Number of threads	3-9	1-10
Thread height	4-5	4-12
Number of counter-rotating pins	2-16	0-38
Application	Steel pipe pile	Steel pipe pile Steel pipe sheet pile
Margin in the strength of joint	1.1	1.2
Total length	190 mm-400 mm	171 mm-401 mm

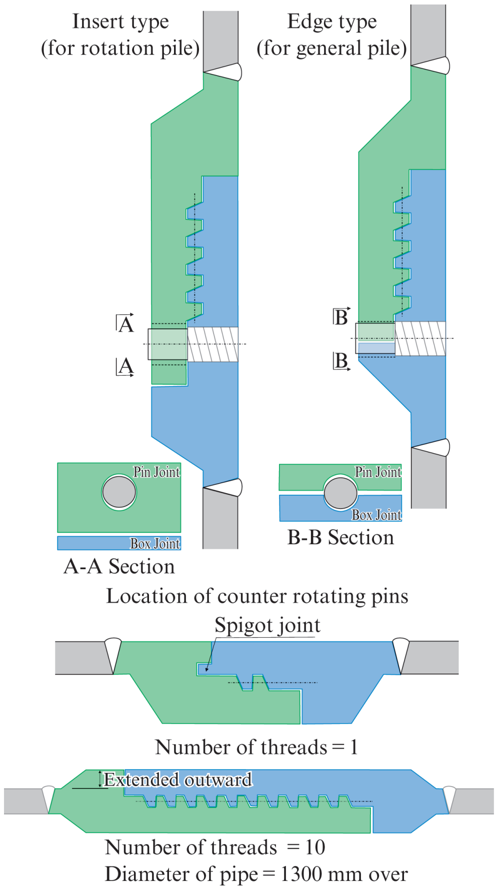

Fig. 2 New design of "High-Mecha-Neji™"

height is 12 mm, depending on the pipe diameter.

(3) As piling methods, pile installation using a vibro hammer and pile installation using a hydraulic hammer were added, and for rotary penetration piles, allowable torque of the joint was substantially increased.

(4) "High-Mecha-Neji" can now be applied to steel pipe sheet piles as well as steel pipe piles.

2.3 Addition of New Structures

To satisfy the development concept, the new designs shown in **Fig. 2** were added. Their performance was verified by tests and analysis. The outlines of these designs are presented below.

(1) Adoption of large counter-rotation pins and change of installation position

Because rotary penetration pile requires high torque, large pins were adopted, and the maximum number of pins was also increased. This specification is called the "Insert type." For construction methods in which virtually no torque acts on the joint during construction, a structure in which the pin joint openings for counter-rotation pins are formed by notches was added, and the joint was shortened. This is called the "Edge type."

(2) Spigot joint

In order to increase deformation performance under bending action when the number of threads is 1, a spigot joint structure was adopted in the bearing surface of the joint.

(3) Extended outward structure

For piles with a diameter of 1 300 mm or larger and the maximum wall thickness, a structure which is extended on the outward side was adopted in order to improve the bending performance of the joint. The amount of this extension was set at a uniform 9 mm so as not to affect shaft friction.

3. Setting of Joint Specification and Verification of Structural Performance

3.1 Outline

Basically, the design method of the conventional type "High-Mecha-Neji" is used. In the case of compressive and tensile load, the influence of joint dimensions is considered negligible, as the load transfer mechanism is uniform in the circumferential direction. On the other hand, bending and shearing performance may conceivably be affected by the joint dimensions and new structures; experimental and analytical studies were conducted to clarify this point.

It may be noted that this report only describes the study of bending performance. However, shearing performance was also evaluated based on similar studies.

3.2 Study Flow

The flow of the study of bending performance was as follows.

i) Bending test and evaluation of bending strength

The influence of the joint parameters (diameter, thread height, number of threads, new structure, number of starts) and whether the maximum strength of the test specimen satisfies the design strength are confirmed.

ii) Verification of appropriateness of Finite Element Analysis (FEA)

The bending test results are reproduced by FEA.

iii) Setting of joint specification

The joint specification corresponding to the diameter, wall thickness and material of the steel pipe pile is set based on the design strength.

iv) Verification of joint performance by FEA

Using the FEA technique verified in ii), the strength of the joint specification set in iii) is confirmed.

Table 2 List of 4point bending tests

Test No.	Joint type	Pipe spec.	Focus point of joint	Simulation	Strength ratio (test/design)	fracture location
1	Conventional type	D318.5-t12 SKK490	minimum diameter reversed cyclic number of threads = 4		1.214	-
2		D800-t25 SKK490	maximum diameter of thread height = 4 mm number of threads = 9	FEM	1.004	-
3		D1200-t28 SKK490	maximum diameter of thread height = 5 mm number of threads = 6		1.039	-
4	New type	D1500-t30 SM570	maximum thickness and grade extended outward number of threads = 10	FEM	1.284*	pipe
5		D700-t16 SKK490	number of starts = 8 number of threads = 2		1.632	joint
6		D700-t16 SKK490	spigot joint number of starts = 8 number of threads = 2		1.728	-
7		D1000-t16 SKK490	number of starts = 8 number of threads = 2	FEM	1.028	joint
8		D1000-t16 SKK490	spigot joint number of starts = 12 number of threads = 1		1.364	-
9		D2000-t20 SM570	maximum diameter maximum thread height (12 mm) spigot joint number of starts = 16 number of thread = 1	FEM	1.043	-

* maximum load in FEM with elastic pipe (because of fracture of pipe)

3.3 Bending Test and Verification of Appropriateness of FEA (i), ii))

4-point bending tests of the total of 9 specimens shown in **Table 2** were conducted, and the tests of four of those specimens were reproduced by FEA. The selection of the test specimens for the FEA was based mainly on the following points.

(1) Confirmation of strength of the joint with maximum diameter (2 000 mm), maximum wall thickness and material specification (30 mm, SM570)

(2) Confirmation of strength of the joint with maximum thread height (12 mm) and maximum number of thread starts (16, lead angle ≒ 4.5°)

(3) Confirmation of influence of spigot joint structure (number of threads: 1) and extended outward structure (number of threads: 10)

Confirmation to ultimate strength was performed with only two specimens. However, the results of all tests confirmed that the joint strength or maximum load satisfied the design strength. Because the steel pipe fractured before the joint in the case of specimen No. 4, the FEA was conducted, in which the steel pipe was treated as an elastic body, and the results of a comparison with the obtained joint strength were shown.

As a typical example of the bending test, **Fig. 3** shows the outline and results for specimen No. 7. This figure also shows the FEA results. It was confirmed that the behavior of the joint can substantially be reproduced by FEA.

In the FEA, an elastoplastic analysis was performed using 3-dimensional solid elements based on the material test results of the joint and steel pipe. A model that considered contact and friction between joints was used. The thread shape was treated as axially symmetrical, and based on the assumption of symmetry, a 1/2 model was used.

3.4 Setting of Joint Specification (iii))

Based on the design strength, the specifications of the joints were set corresponding to the specifications of the steel pipes. The main setting items are shown in **Fig. 4**.

Two types of specifications were set for the joints corresponding to the specification of the steel pipe. Series J is a specification for steel pipe piles, and series K is a specification for steel pipe sheet piles (for thin thickness SKK400 and SKK490, small rotation). Options can be selected as follows, corresponding to

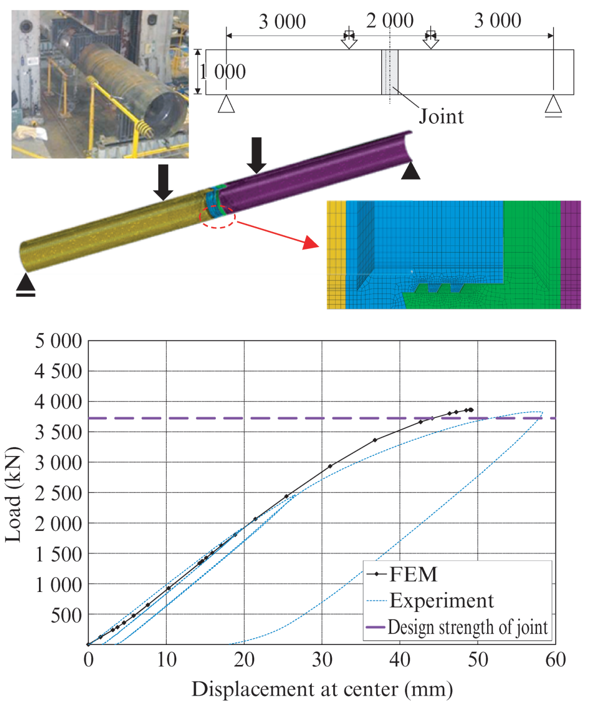

Fig.3 Overview and result of bending test and analysis

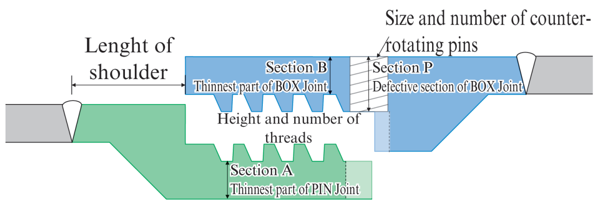

Fig.4 Setting of joint specification

the construction conditions.

(1) Counter-rotation pin specification

The number and position of the counter-rotation pins was set corresponding to the necessary torque. In setting the joint specification, the maximum number of counter-rotation pins was supposed.

(2) Number of starts

The standard specifications are 4 starts for steel pipe piles and 8 starts for steel pipe sheet piles. However, in cases where it is necessary to reduce the number of jointing turns due to site conditions, the limitations of the construction machinery or the like, it is possible to increase the number of starts.

3.5 Joint Performance Verification by FEA (iv))

Series J provides 5 to 7 setting specifications and series K provides 1 or 2 setting specifications for each pipe diameter, for a diverse range totaling 171 setting specifications.

Since it would be difficult to conduct an analysis of all of these specifications, FEA was performed for representative specifications corresponding to the steel pipe diameter, number of threads, thread height and new structures (7 specifications for series J, 4 specifications for series K).

The FEA model used in this analysis was the same as the 4-point bending model in section 3.3 (distance between loading point: 2.0D (D = diameter of steel pipe), arm length: 4.0D). The joint was modeled as a bilinear elastoplastic body using the standard yield point (685 N/mm^2), and the steel pipe was modeled as an elastic body of the maximum wall thickness at maximum strength), and the bending strength of the joint was calculated based on these conditions.

Table 3 shows the positions of the analyzed joints in the applicable range and the specifications and bending strengths of the joints.

Figure 5 shows the load displacement curves for the span center obtained by the analysis when the load was normalized with the full plastic strength of the steel pipe and the displacement at the span center was normalized with the calculated bending and shear defor-

Table 3 Analyzed joint specification

Strength of joint		weak←			→strong
Number of threads		few←			→many
Spec. thickness (mm)	SKK400	6-16	17-35	36-52	53-60
	SKK490	6-12	13-28	29-38	39-45
	SM570	6-8	9-20	21-26	27-30
Diameter (mm)	900	J900A K900Z*1		J900G	-
	1 000				
	1 200	J1200A	J1200Y		J1200G
	1 500				
	2 000	K2000Z*1	J2000A K2000Y	J2000E	J2000G*2

*1: spigot joint
*2: extended outward

Joint series	Name	Number of threads	Thread height (mm)	Thickness of pipe (mm)	Bending strength (kNm)
J	J900A	2	5	6-SM570	2 590
	J900G	10	5	26-SM570	10 728
	J1200A	2	6	7-SM570	5 380
	J1200G	10	6	30-SM570	22 181
	J2000A	2	8	9-SM570	19 266
	J2000E	6	8	25-SM570	52 661
	J2000G	10	8	30-SM570	62 875
K	K900Z	1	10	10-SKK490	2 994
	K1200Y	2	10	18-SKK490	9 507
	K2000Y	2	12	21-SKK490	31 090
	K2000Z	1	12	12-SKK490	17 927

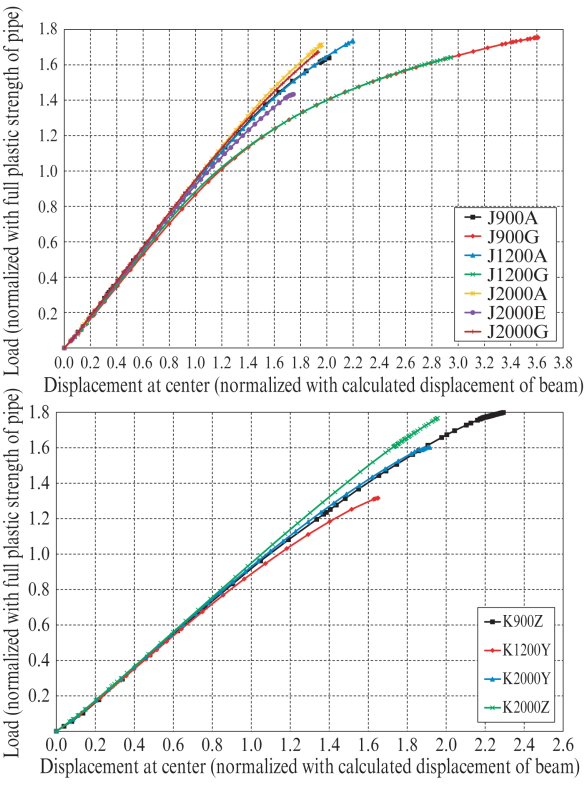

Fig. 5 Normalized load-displacement curve

mation of the beam. The analysis was terminated with the load transfer of the joint became unstable in the entire test specimen.

The strength of all specifications is at least 1.2 times that of the steel pipe, and the stiffness of the steel pipe with the joint is substantially the same as that of the steel pipe alone, confirming that the joint specifications have adequate strength for the steel pipes.

4. Verification of Construction Performance

4.1 Outline

Jointing and construction tests of the joints were conducted to confirm that jointing time can be shortened in comparison with welding and the joints are also without damaging when used with the newly-added construction methods.

4.2 Jointing Time

The time required for jointing was investigated using joints from the smallest to the largest diameter. The results of a comparison with the welding time calculated based on estimation standards are shown in **Table 4**.

Table 4 Lead time of jointing

	Pile spec.		Joint time	Welding time*1	A/B
	Diameter	Thickness	A	B	
	mm	mm	min	min	
Test1	318.5	12	5	22	0.21
Test2	609.6	9.5	2	33	0.06
Test3	800	13	8	46	0.16
Test4	800	16	12	59	0.20
Test5	800	25	6	83	0.08
Test6	1 000	12	4	44	0.10
Test7	1 200	25	10	125	0.08
Test8	2 000	20	3	208	0.02

*1: estimation standard of public works

Although there were some variations, the joints were completed in roughly less than 10 min, confirming a large time saving (reduction of jointing time to 1/5 or less) in comparison with welding. Furthermore, the time saving effect became larger as the diameter increased.

4.3 Application to Vibro Hammer and Hydraulic Hammer Methods

Construction tests by the vibro hammer method and the hydraulic hammer method were carried out using new “High-Mecha-Neji”. The specification of the test pile and the construction conditions are shown in **Table 5**, and the condition of the construction tests is shown in **Photo 2**.

For severe conditions of the joints, the vibro hammer test was carried out for approximately 60 min, which is the guideline for the longest construction time in the Pile Foundation Construction Handbook[4]. In the hydraulic hammer test, the pile was penetrated approximately 1.2 m into ground having an N value of 50 or more.

To prevent loosening of the counter-rotation pins during pile installation, the pins were coated with a special nylon coating, as shown in **Photo 3**, and were then tightened with a constant torque (50 N·m).

After construction tests, the joints were removed

Table 5 Specification of test pile and construction condition

Pipe spec.	Hammer type	Machine spec.	Construction condition
*D*700 mm *t*12 mm	Vibro hammer	Motor 120 kW Vibratory force 748 kN Frequency 16 Hz	Vibratory force 748 kN Driving time 11 min. (N<50) 56 min. (N>50)
*D*600 mm *t*9 mm	Hydraulic hammer	Ram weight 10 ton Driving energy 150 kNm	Driving energy 40 kNm Total number of impacts = 534

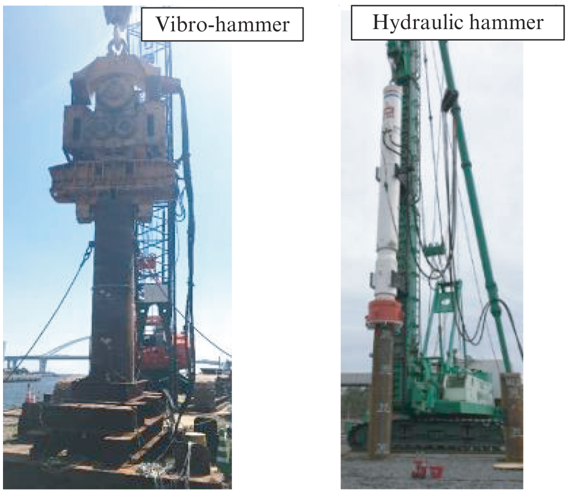

Photo 2 Constructing test of "High-Mecha-Neji™"

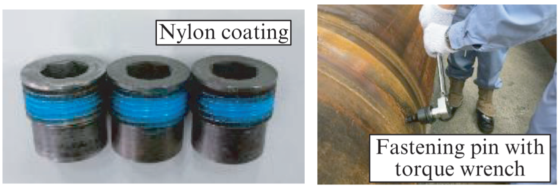

Photo 3 Prevention of slack for counter rotating pins

and the inside condition of the joints was checked. Because no damage or deformation of the thread parts was observed and jointing of the tested joints could be performed again, the applicability of new "High-Mecha-Neji" to the vibro hammer and hydraulic hammer methods was also confirmed.

4.4 Application to Steel Pipe Sheet Piles

When using steel pipe sheet piles, the most important point is aligning the direction of the connecting joints on the two sides of the steel pipes in the upper and lower pipes. Therefore, steel pipe sheet piles with joints were actually manufactured in order to verify the correct alignment of the connecting joint direction after completion of jointing of the new "High-Mecha-Neji".

The specification of the test pile is shown in **Table 6**. The threaded part has 8 starts and 2 threads, and jointing is completed by turning 90°. As shown in **Photo 4**, jointing was completed with no problems.

To prevent deformation of new "High-Mecha-Neji", welding of the connecting joints and steel pipe near the mechanical joint was omitted.

4.5 Torsion Test

A torsion test of a joint with the notch structure as the hole for the counter-rotations pins was carried out using an actual pile driving machine. The outline of the test and test results are shown in **Table 7** and **Fig. 6**, respectively.

The joint behaved elastically until it reached the torsional strength corresponding to the number of counter-rotation pins, confirming that the joint with

Table 6 Specification of test pile

Pipe spec.	Number of starts	Number of threads	Thread height
*D*1 000 mm-*t*12 mm	8	2	8 mm

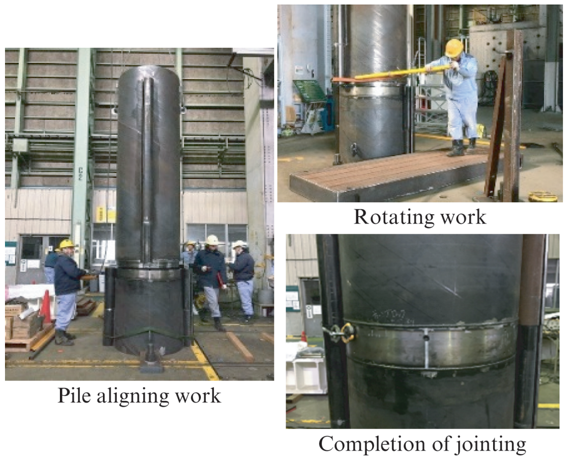

Photo 4 Jointing of steel pipe sheet pile

Table 7 Specification of test pile

Pipe spec.	Number of starts	Number of threads	Thread height
*D*700 mm-*t*16 mm	4	4	4 mm

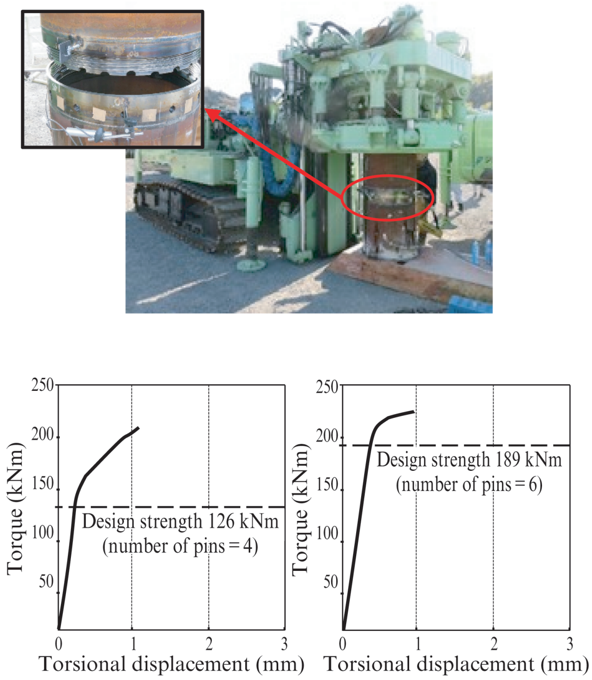

Fig. 6 Overview and result of torsion test

the notch structure can also demonstrate the specified strength.

5. Conclusion

This report described the development of new "High-Mecha-Neji", which is a mechanical joint for steel pipe piles and steel pipe sheet piles. More detailed information can be found in the report[5] of Construction Technology Review and Certification by the Public Works Research Center.

As a result of a large expansion of the applicable range of new "High-Mecha-Neji", these mechanical joints can be used under conditions that were impossible with conventional joints. In the future, we will work to achieve further dissemination of this technology.

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