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Mechanical Joint "KASHEEN" for Large-Diameter Pipe Piles†

AKUTAGAWA Hiroaki[*1] TAKANO Kimitoshi[*2] TAJIKA Hisakazu[*3]

Abstract:

JFE Group has developed a mechanical joint, "KASHEEN," for large-diameter steel pipe piles. Through a series of bending tests and FEM analysis on the steel pipe piles with the mechanical joint, it is confivined that the joint has larger strength than the body of a pile. A full scale construction test of the joint part proved the reduction of construction time. And pile-driving test proved good field performance, such as no risible deformation of the pipe, no loosening of bolts and no impact on construction efficiency.

1. Introduction

Formerly, the joining works of steel pipe piles were generally performed by field welding. However, since such welding has the problems (1) that the execution time is comparatively long and this tendency increases as the external diameter or wall thickness of the steel pipe increases, (2) that the work cannot be executed under bad weather conditions; such as rain, strong wind, etc., (3) that careful control and highly skilled welders are required to ensure the quality, and other problems. These problems have been major causes of lengthened construction periods and increased construction costs, due to the recent tendency to use larger diameter and thicker walled steel pipe piles, the increasing frequency of construction works in narrow sites, and of others problems.

Considering the above mentioned background, the JFE Group has developed "KASHEEN," non-welded mechanical joints applicable to large diameter, thick steel pipe piles and its practical use has been realized.

This paper describes the introduction of the joint shapes and load transfer mechanisms, the results of strength tests and finite element method (FEM) analysis, and the conditions of the construction tests and actual operations.

2. Outline of KASHEEN

The structural outline of the KASHEEN system is shown in **Fig. 1**. KASHEEN is produced by forging and machining high tension 780 MPa class, JFE-HITEN780 steel. The joint portion consists of a pin and a box joint, and each of these joints is pre-welded to the ends of steel pipe piles in the shop. The details of the structure of the pin and box joints are as follows:

Pin Joint: This joint has a clincher rim and is circumferentially divided into 8 parts with slits provided. Bolt

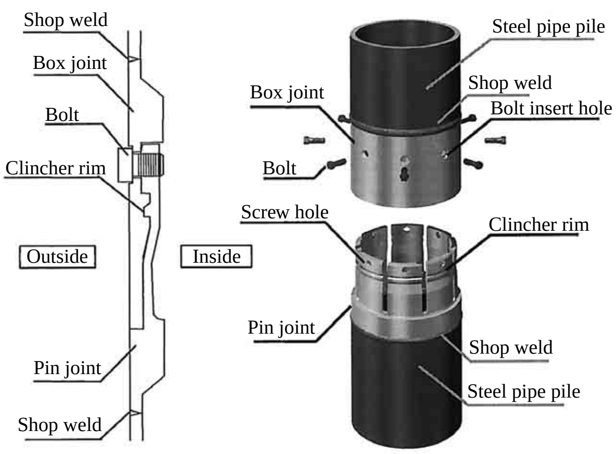

Fig. 1 Mechanical joint "KASHEEN"

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*2 Staff General Manager,
Construction Materials & Structures Dept.,
Material Technology Div.,
JFE Techno-Research


*1 Staff Deputy Manager,
Civil Engineering, Sec.,
Construction Engineering Services Dept.,
Construction Material & Services Center,
JFE Steel


*3 Senior Researcher Deputy Manager,
Civil Engineering Dept.,
JFE R&D

screw holes are provided in the uppermost portion of the joint.

Box Joint: This joint has a concave portion inside the joint, which corresponds to the clincher rim of the pin joint, and the bolt insert holes are provided for the penetration of bolts corresponding to the locations of the bolt screw holes of the pin joint.

The joining procedure of KASHEEN is as follows.

(1) Put the box joint end of a steel pipe (upper pile) onto the pin joint end of another steel pipe (lower pile).
(2) The uppermost portion of the pin joint is inserted into the center side of the joint with deformation, by the own weight of the upper pile or by introducing a tensile force between the upper and lower piles.
(3) The insertion is completed, when the lower end of the box joint strikes the pin joint.
(4) Pull the pin joint to the side of the box joint, by inserting the bolts into the bolt insert holes of the box joint and into the bolt screw holes of the pin joint and tightening these bolts.
(5) The joint is completed, by giving sufficient bolt tightening torque and engaging the clincher concave and convex portions of the box joint.

Furthermore, the qualification scope by the Construction Technology Review and Certification[1] of Public Works Research Center and by the Examination and Evaluation of Coast-related Technologies in the Private Sector[2] of Coastal Development Institute of Technology is 400–1 600 mm outside diameter (ϕ) steel pipe piles and steel pipe sheet piles of 6–30 mm in wall thickness, and the applicable construction techniques of the pile is pile installation by the inner excavation method, the hybrid-steel pile and soil cement-pile method, the press-in piling method and the pile-driving method.

3. Strength Confirmation Test

3.1 Outline

It was confirmed, by carrying out the experiments and analysis that the KASHEEN system possesses the expected strength.

Table 1 shows the experiments and analysis that were carried out. At this time, the tests carried out were the compression test, tensile test, bending-shear test and bending test for the KASHEEN joint itself, and bending test for steel pipe with a KASHEEN joint. This paper reports on the bending test results of KASHEEN steel pipes of ϕ1 600 × t25 mm which is the largest diameter of the above mentioned tests. In addition, the analysis of various diameters and wall thicknesses of steel pipes were carried out, by simulating the bending test for steel pipes with KASHEEN joints. This paper shows the results on the largest diameter and the largest wall thickness (ϕ1 600 × t30 mm) in the applicable scope, out of the various above mentioned analysis.

Table 1 List of experiments and analysis

Type of experiment	Specimen (mm)
Compression	ϕ 600 × t12
Tensile	ϕ 267.4 × t 9
Bending-shear	ϕ 267.4 × t 9
Bending	ϕ1 600 × t25
	ϕ1 200 × t25
	ϕ 600 × t12
Bending (FEM)	ϕ1 600 × t30
	ϕ1 600 × t25
	ϕ1 200 × t25
	ϕ 800 × t25

3.2 Bending Test for Steel Pipes with KASHEEN Joints

It was confirmed by the bending test using full scale specimens that the steel pipes with KASHEEN joints possess the required bending strength.

The test method is the four-point bending test shown in **Fig. 2**, and the KASHEEN joint was located at the center of the loaded width, where the maximum bending moment is generated. **Table 2** shows the materials used and their dimensions. The earthquake allowable load of steel pipes of (ϕ1 600 × t25 mm) is 4 848 kN if converted into an applied load, the load at which the steel pipe yields due to bending (yield load), Py is 5 493 kN, and the load at which the steel pipe cross section becomes fully plastic (full plastic load), Pp is 7 104 kN. During the bending test, these loads are unloaded once

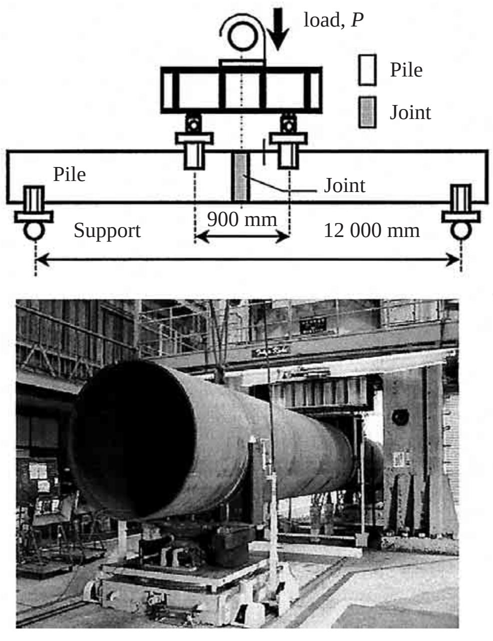

Fig.2 Bending test (ϕ1 600 × t25 mm)

Table 2 Mechanical properties

Part	Pile	Joint
Material	SKK490	JFE-HITEN780
Young’s ratio (N/mm^2)	2.0×10^5	
Poisson’s ratio	0.3	
Yield stress (N/mm^2)	315	685
Tensile stress (N/mm^2)	490	780

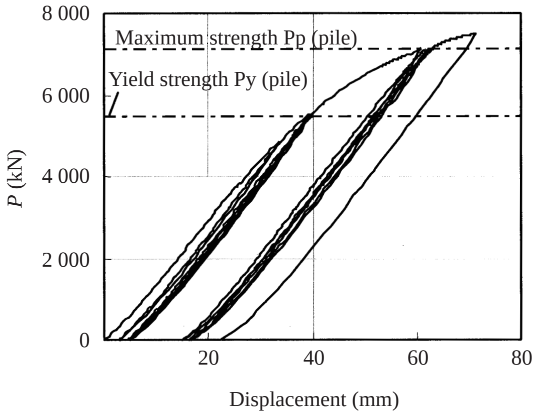

Fig. 3 Load-deformation curve

and then they are loaded with the target load, to understand the influence on the behavior of the applied load. Furthermore, the yield load and the full plastic load were loaded 3 times each.

Figure 3 shows the test result (load-deformation curve). For the steel pipes with KASHEEN joints, the residual deformation due to loading of the earthquake allowable load and yield load is small and the steel pipe is still sound within the range of these loads. In addition, though the residual deformation amount due to full plastic load loading increases slightly, the progress of residual deformation is small even if the loading is repeated. From the above, it could be confirmed that a KASHEEN joint has sufficient strength under bending loads.

3.3 Analysis of Steel Pipe with KASHEEN Joints

To verify the bending strength of steel pipes with KASHEEN joints, the strength was analytically confirmed for the largest and thickest steel pipe (ϕ1 600 × t30 mm) applicable to the KASHEEN system, as well as being experimentally verified.

The conditions of the materials (Table 2), shapes, boundary conditions, etc. were modeled in the same manner as the experiment (Fig. 2). As for the element division (**Fig. 4**), detailed modeling was carried out near mechanical elements, bolts, etc. exist in the joint portion (KASHEEN), and the modeling for the steel pipe portion was carried out with rough element division.

The load Py when steel pipe of ϕ1 600 × t30 mm yields due to bending is 6 519 kN if converted into an applied load, and the load Pp when the cross section of the steel pipe becomes fully plastic is 8 472 kN. The analysis was executed with these loads considered as the target loads.

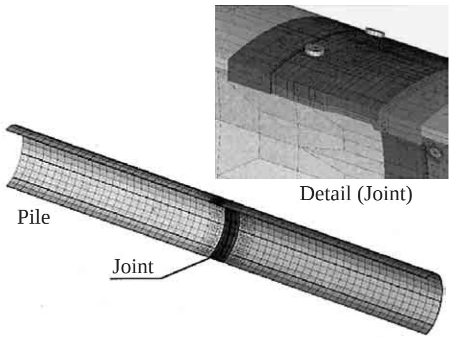

Fig. 4 FEM model (ϕ1 600 × t30 mm)

The analysis result (load-deformation curve) is shown in **Fig. 5**. It is clear that the steel pipe with KASHEEN joints is sound even if the yield load of the steel pipe is exceeded. From the above, it has been confirmed that the strength of KASHEEN exceeds that of the body of the steel pipe. In addition, a reduction of the bending moment was not observed even when the full plastic load is exceeded and the maximum load is reached, and it has been confirmed that a reduction of strength of KASHEEN did not occur.

Furthermore, **Fig. 6** shows the distribution diagram of stress generated in the KASHEEN joint during loading of the yield load of the steel pipe. Due to bending, tensile stress is generated on the side of the support, and compressive stress on the side of the loading point. As the tensile stress is prominent at the thinnest portion of the pin joint, the distribution inside the joint is shown for the tension side, while the distribution outside the joint is shown for the compression side because the compressive force is transmitted owing to the striking contact between the tip of the box joint and the shoulder portion of the pin joint.

On the tension side, a big tensile stress is generated along the portion from the coordinates 200 mm to

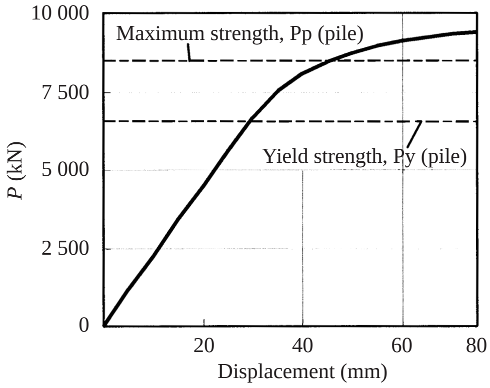

Fig. 5 Load-deformation curve (FEM)

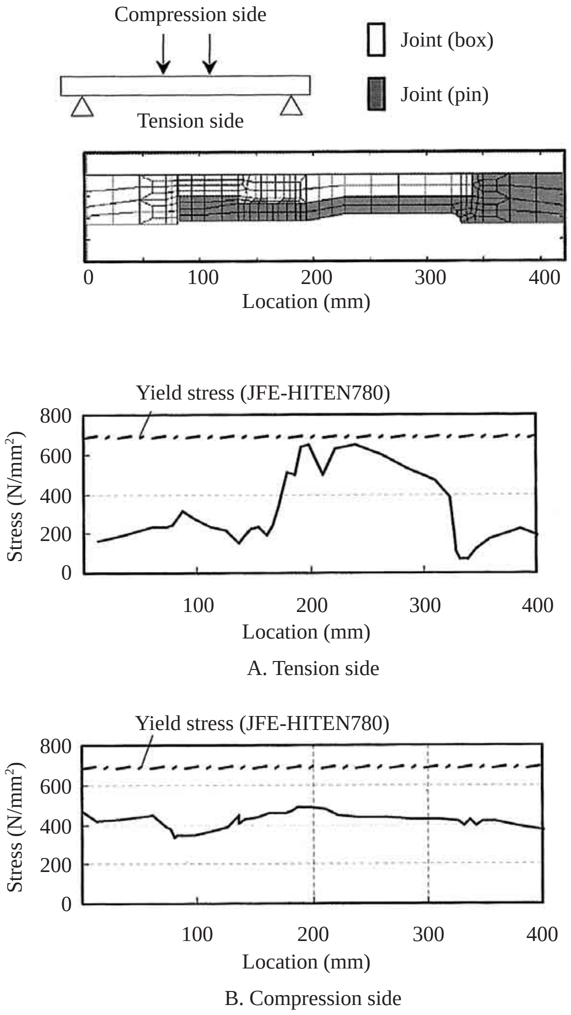

Fig. 6 Stresses in joint elements

300 mm. This portion is assumed as the critical cross section during tension in the design, and it shows that the setting of the critical cross section in the design is appropriate. Furthermore, when the yield load of the steel pipe was applied, a stress exceeding the material yield stress of JFE-HITEN780 was not generated. On the other hand, as for the compressive stress, this type of stress was generated uniformly in the box joint. Also as for the compressive stress, a stress exceeding the material yield stress of JFE-HITEN780 was not generated, when the yield load of the steel pipe was loaded.

From the above, it could be confirmed that the steel pipe with KASHEEN possesses the expected bending strength, also for the case where the yield load of the body of the steel pipe was applied.

3.4 Summary

It was confirmed by these experiments and analysis that the strength of KASHEEN equals or exceeds that of the body of the steel pipe and exceeds the required strength. Accordingly, steel pipe piles with KASHEEN joints can be used without any problem under the design conditions.

4. Construction Test

4.1 Outdoor Joint Test

The joint test of the joints was carried out by using full size steel pipes, in order to confirm the constructibility of KASHEEN joints. **Table 3** shows the joint test cases and the test results. The test was executed, by using KASHEEN joints for steel pipe of $\phi 1\,600 \times t25$ mm in Case 1, that for $\phi 1\,200 \times t14$ mm in Case 2, and that for $\phi 400 \times t8$ mm as an example of a small diameter pile in Case 3.

During the test, the box joint was inserted, by gradually applying the own weight of the upper pile lifted by the crane onto the lower pile (box joint side) as shown in **Photo 1**. As the insertion can be completed in a short time and the joint is completed only by tightening the joint bolts after insertion, very excellent constructibility results could be obtained in all cases.

The measured times required for the individual joining works during the outdoor joint test were: time from the alignment of joints to the insertion was approximately 3 min regardless of the diameters of steel pipes and then the total joining work was completed within approximately 10–15 min as a result, though there was a difference of the time for the joint work varying according to the number of joint bolts. Table 3 shows the measured times, which were calculated based on the estimation standard, as a reference for comparison with the times to join the joints. When comparing both

Table 3 Joint test results

Case	Steel pipe specification		Number of bolts	Process time (KASHEEN)	Process time (Field weld)*
	Diameter (mm)	Thickness (mm)			
1	ϕ1 600	25	16	11 min 22 s	188 min
2	ϕ1 200	14	32	15 min 23 s	61 min
3	ϕ400	8	8	11 min 32 s	13 min

* Process time is calculated based on the estimation standard.

Photo 1 Insertion situation of KASHEEN

process times, for the steel joint by field welding, the process time increased rapidly as the steel pipe diameter and the wall thickness increased, while, the results of the joint test by KASHEEN executed at this time, an almost constant joint time was maintained for all diameters and a significant result showing the reduction of construction time of the KASHEEN system was obtained.

4.2 Applicability of Impact Hammer and Vibro Hammer

In order to confirm the applicability and the behavior during construction for the impact method and the vibro method of KASHEEN, the construction test was carried out by using KASHEEN for a steel pipe of ϕ1 200 × t14 mm. **Table 4** shows the specifications of the heavy equipment used, **Table 5** the construction conditions, and **Photos 2** and **3** the test situations.

As KASHEEN might be deformed and the joint may be damaged due to directly impacting KASHEEN during construction with impact and vibro methods, the standard construction method is to execute the construction work with a protective cap attached. Accordingly, when studying the applicability of KASHEEN to the vibro and impact methods, it was determined to verify the generated stress intensities of KASHEEN and the occurrence of loosening of joint bolts, paying attention to the case where protective caps are used and the condition of joined piles. The following explains the test results.

(1) Protective Cap

As a result of construction with protective caps attached to KASHEEN, deformation at the joint portion was not recognized in either the impact or vibro methods, and the joining of joints could be smoothly carried out after removal of the protective caps.

Photo 2 Vibro method test (Used protection cap)

Photo 3 Impact method test (Use protection cap)

Therefore, it could be confirmed that KASHEEN can be applied to steel pipes constructed by both the vibro and impact methods by adopting protective caps.

(2) Joined Piles

After jointing piles using KASHEEN joint and after verifying the pile reaches the bearing stratum, the authors checked the stresses at joint during construction. **Figures 7** and **8** show the stresses respectively by vibro-hammer (120 kW class:approximately 40 min) and impact hammer (100 kW class hydraulic hammer: approximately 60 min). Generated stress

Table 4 Specifications of heavy equipment

Method	Kind of heavy equipment	Specifications
Vibro Method	Motorized vibro-hammer	120 kW class Vibratory force: 748.2 kN Frequency: 16.3 Hz (58 680 times/h)
Impact Method	Hydraulic pile hammer	Ram weight: 10 t Driving energy: 141 kN·m

Table 5 Specifications of pile-driving test

Case	Diameter (mm)	Condition of KASHEEN	Method	Conditions of performance
1	ϕ1 200	Use protection cap	Vibro method	Time: T = 1 000 s (20 min) Number of vibrations: T × 16.3 = 16 300 times
			Impact method	Ram fall height: Level 1–8 Number of blows: 800 times (30 min)
2	ϕ1 200	State of joint	Vibro method	Time: T = 2 400 s (40 min) Number of vibrations: T × 16.3 = 39 120 times
			Impact method	Ram fall height: h = 1.44 m (Maximum) Number of blows: 900 times (60 min)

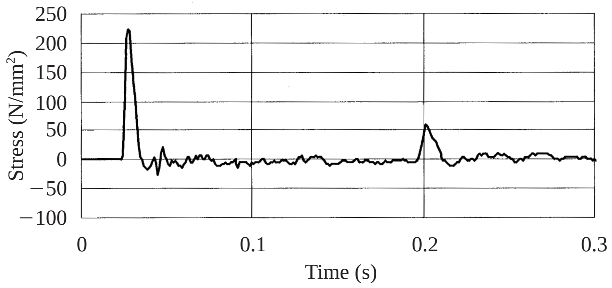

Fig. 7 Stress of Impact method test

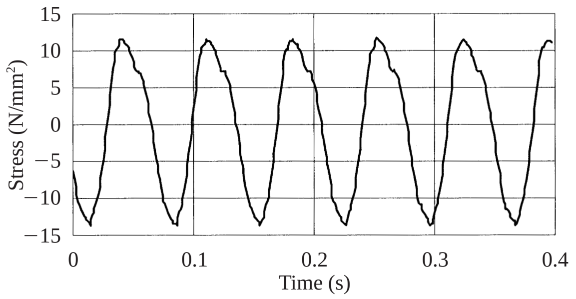

Fig. 8 Stress of vibro method test

by vibro-hammer was ±15 N/mm^2, and that is 3% of the yield stress of KASHEEN (S_{yj}: 685 N/mm^2). And generated stress by impact hammer was 223 N/mm^2 at the maximum, and that is 33% of the yield stress of KASHEEN. From these results, it was confirmed that the stresses were within the material's range.

In addition, when joint bolts were found to have loosened due to impact and vibration, the occurrence of large loosening was not observed, at the bolts which had been tightened with sufficient torque (torque value = 150 kN · m) and at the locations where locking bolts had been used.

Furthermore, **Fig. 9** shows the change of acceleration measured during construction by the vibro method on the upper and lower sides of the joint. As the change of acceleration does not change significantly on the upper and lower sides of the joint and the vibration is transmitted sufficiently even through the joint, it is understood that KASHEEN has no negative effect on construction efficiency.

In addition, as for the specimens used for the impact and vibro tests at this time, the steel pipes with KASHEEN were subjected to bending tests after the withdrawal of the steel pipe piles and it was con-

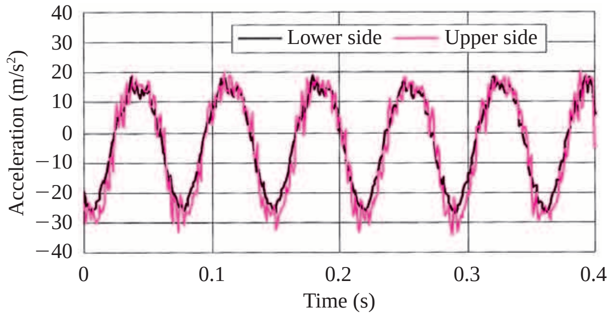

Fig. 9 Acceleration of vibro method test

firmed that the specified strength of KASHEEN can be obtained even after having been subjected to the hysteresis of impact and vibration.

From the above-mentioned results, it has been confirmed that the piles joined with KASHEEN possess sufficient applicability to the impact and vibro method.

5. Conclusion

This paper introduced the results of strength confirmation tests and analysis, and the results of joint test for the non-welded mechanical joint, KASHEEN, for steel pipe piles and steel pipe sheet piles.

KASHEEN has already obtained the qualifications of the Construction Technology Review and Certification of Public Works Research Center (Mar. 2004) and of the Examination and Evaluation of Coast-related Technologies the in Private Sector of the Coastal Development Institute of Technology (Nov. 2004).

While the diameter of the steel pipe piles continues to increase, and the construction sites narrow greatly in the future, we are sure that the needs to use KASHEEN, which enables very convenient work to complete the joint works of steel pipe piles and assures the strength of the joint portion, will grow as a product to develop new possibilities to the construction sites of steel pipe piles.

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