Development of a New Mechanical Joint for Steel Pipe Piles and Steel Pipe Sheet Piles(Laqnican Joint Step Type)

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Generally, steel pipe piles and steel pipe sheet piles are connected to each other by welding vertically in the field and buried to the bearing ground. Recently, mechanical joints have started to become widely used as a method of connecting steel pipe piles easy in a short time. A mechanical joint has some advantages in addition to speed connection but since our conventional product is more expensive than welding, it doesn't meet the needs of our customers. Now, Kubota has improved the material, manufacturing method and structure of our conventional product to develop a new model mechanical joint which has low costs and meets the needs of customers. As a result of the present development, Kubota has succeeded in obtaining an order from overseas for mechanical joints for the first time and made a great contribution to the spread of mechanical joints.

【Key Word】
Pile Foundation, Steel Pipe Pile, Steel Pipe Sheet Pile, Mechanical Joint, Press Bending, Annealing

Related SDGs

1. Introduction

Steel pipe piles and Steel pipe sheet piles are widely used as construction materials for civil engineering structures (Roads and Railway bridges, Port facilities, etc) and building structures (Logistics warehouse, Condominiums, etc) because of their excellent seismic performance and workability.

In construction, it is common to place and bury multiple steel pipes carried in a construction site to the predetermined depth while welding and joining them. Although this welded joint (Hereinafter referred to as "joint by welding".) is inexpensive, the quality of the weld depends largely on the skill of the worker and also depends on the work environment and weather conditions because of the welding work on the construction site.

In addition, in terms of quality control, strict quality control is required for the joints by welding.

In recent years, there has been a tendency to adopt steel pipe piles and steel pipe sheet piles with larger diameters and thicker plates than in the past. Therefore, the time required for welded joint and quality control is increasing, and the shortening of the whole construction time is required.

In addition, Manpower saving, space saving, time saving, and low cost construction technology have been required due to a shortage of skilled workers (Especially welding workers) and an increase in infrastructure renewal work mainly in urban areas.

Mechanical joints for steel pipe piles and steel pipe sheet piles were developed to meet these needs. In particular, in case of Kubota's product named “Laqnican Joint”, easy and short time joining work is possible by covering the inserting joint called Pin joint with the accepting joint called Box joint and pushing out Load-transfer key stored in Box joint (Fig. 1). However, since mechanical joints has been more expensive than joints by welding, they have been used only in special market (Hereinafter referred to as “special market”) such as night time construction with time constraints (e.g. Railway construction that requires completion of construction within the time from the departure of the last train to the departure of the first train.) and construction with space constraints under bridge girders (Extremely narrow road works under bridge girders of urban expressways).

In order to make mechanical joints more popular, it is required for us to enter not only existing special market but also general pile market (Hereinafter referred to as "general market").

And it was necessary to review material and structure of the existing mechanical joints and develop a new mechanical joint with overwhelming low cost to make mechanical joints to be adopted widely in the market.

By radically reviewing the materials and structure of the formula joints, we have succeeded in reducing costs by an overwhelming margin.

It was necessary to develop a new type of mechanical joint.

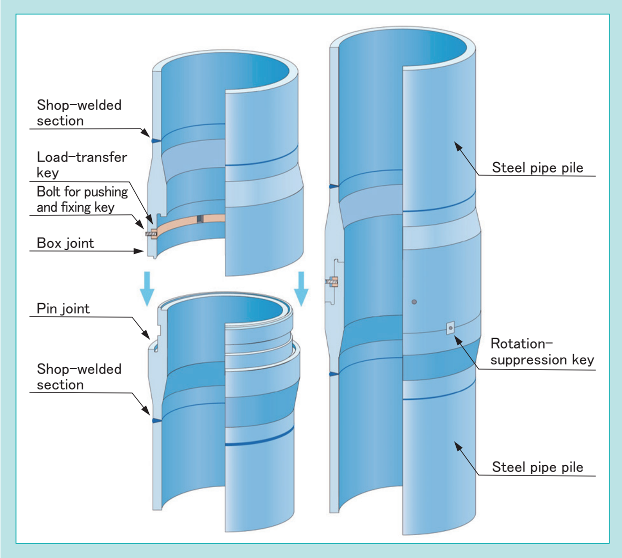

Fig. 1 Mechanical Joint (Laqnican Joint)

2. Development concepts and target values

2 -1 Development Concepts

Kubota started the development of the mechanical joint in 2000 and started to sell the initial model in 2002.

Although the cost reduction was attempted by repeated minor changes afterward, a significant cost reduction was required for further spread of mechanical joints. And we decided to review the material, processing method and whole structure of the existing mechanical joints.

That is, the raw material, the processing method to the ring shape, the heat treatment method and the cutting processing method in the manufacturing process of the mechanical joint were reviewed.

Furthermore, the weight of the mechanical joint itself was reduced and drastic cost reduction was realized by improving the detailed structure of the mechanical joint.

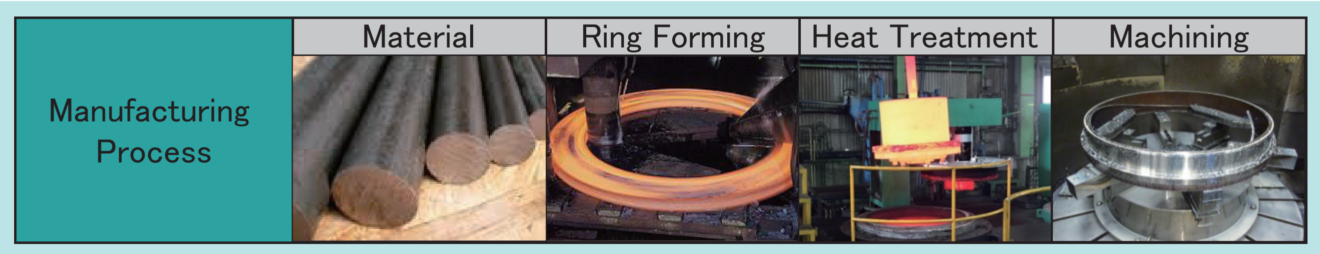

Fig. 2 Manufacturing Process of a Mechanical Joint

2 -2 Target value

It is necessary to replace joints by welding with mechanical joints in general market to make the mechanical joints more popular.

In order to realize it, the cost of mechanical joints has to be reduced until the total cost is equivalent to that of joints by welding.

The total cost consists of the manufacturing cost of the joint and the cost required for joining at the construction site, and especially in mechanical joints, it is possible to reduce the cost at the construction site by shortening the construction period.

Taking into consideration the effect of cost reduction at the construction site, the manufacturing cost of a new mechanical joint becomes equivalent to total cost of joints by welding with 50% reduction from the conventional product.

(Target value) 50% reduction in manufacturing costs of a new mechanical joint compared to conventional product.

3. Technical issues to be solved

3-1 Manufacture of the Industry's First Mechanical Joint using Straight Seam Pipe

In case of conventional mechanical joints, the material (Hereinafter referred to as "forged ring material".) formed by hot forging special steel into a ring shape were used in Japan even though there were problems in procurement and cost due to the material peculiarity. So we tried to use steel pipes (Hereinafter referred to as "Straight seam pipe") manufactured by press bending which is more common machining method to make it possible to procure materials widely from Japan and overseas. Kubota is the first company in the industry to use the straight seam pipe for the mechanical joint material. The straight seam pipe is manufactured by forming a flat steel plate into a cylindrical shape by a uniaxial press machine and welding the ends (Figure 3).

However, since the straight seam pipe used as a material for a mechanical joint is thicker than normal steel pipe for its outer diameter and has high strength, a large strain remains in the ring material during molding.

When it is cut mechanically, the internal stress is released and deformation occurs, then the finished dimension of the mechanical joint tends to vary.

In particular, high dimensional accuracy is required for mechanical joints because they are mechanically engaged and joined at construction sites. Therefore, the issue is how to reduce the residual stress and secure the dimensional accuracy.

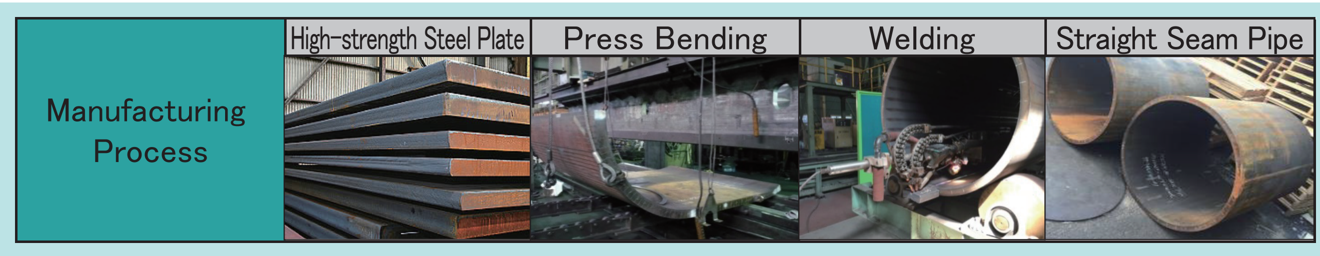

Fig. 3 Manufacturing Process of a Straight Seam Pipe

3-2 Reduction of weight for mechanical joint

Conventional mechanical product was designed with safety in mind more than necessary, and the joints were longer and thicker. This is because the deformation and load of the details in the mechanical joint have not been fully clarified.

Therefore it is necessary to clarify the stress generation mechanism of its detailed structure and to optimize its shape in order to reduce the weight of the mechanical joint.

In a mechanical joint, when a tensile load is applied, the force stress is transmitted through a Load-transfer key (Figure 4). Therefore, the design around the load transmission part is very important for the design of the mechanical joint. In particular, in order to make the mechanical joint thinner and lighter, it is necessary to reconstruct the following design method (Fig. 5). ① Thickness of Groove cross section ② Thickness of Load-transfer Key.

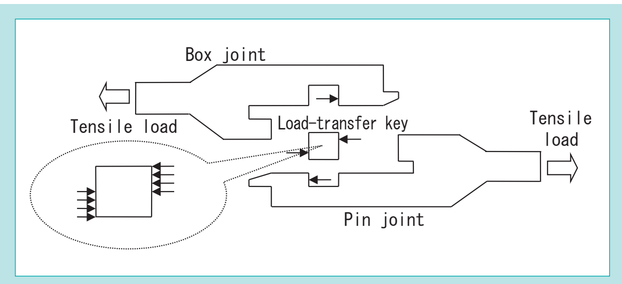

Fig. 4 Force Transfer Mechanism of a Mechanical Joint

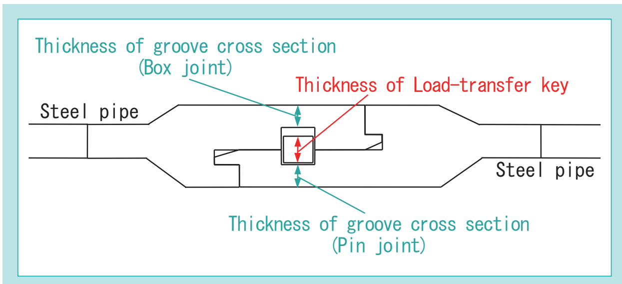

Fig. 5 Design Review Section

3-3 Assurance of Required Performance for Mechanical Joint

Since the new mechanical joint is made of straight seam pipe and is thinner and lighter, it is necessary to verify whether it has the performance required for actual mechanical joint.

And, because the mechanical joint is welded to the main part of steel pipe pile and steel pipe sheet pile at the factory and is used as a part of those products, the mechanical joint is required to have the same or higher strength to the main part of steel pipe pile and steel pipe sheet pile.

The issue is whether this strength can be ensured in the new mechanical joint or not.

4. Development technology

4-1 Development of straight seam pipe with low residual stress

In order to reduce the residual stress of the straight seam pipe, we examined the implementation of annealing. Annealing is effective in reducing residual stress because it softens the texture of the material, but at the same time, it may reduce the tensile strength of the material. Therefore, an element test was conducted in advance to verify an appropriate annealing temperature that does not decrease the tensile strength. From the test results, it was confirmed that the strength did not decrease up to 600℃. This was set as the upper limit temperature of the annealing temperature.

In addition, it was verified that the residual stress was reduced to the extent that the accuracy of the finish dimension of machining could be maintained by the annealing.

The machining was carried out using straight seam pipe with different annealing temperature, and the dispersion Dmax-Dmin (Hereinafter referred to as "circularity") of the outer finish dimension was verified (Figure 6).

The roundness of the finished product was within the allowable value when annealed at 600 ℃. Annealing showed that the straight seam pipe could be applied as a material for mechanical joints.

For reference, we tried to quantify how much residual stress was reduced by annealing.

The residual stress before and after heat treatment was measured by X-ray stress measurement method, and it was confirmed that the residual stress was reduced by annealing (Figure 7).

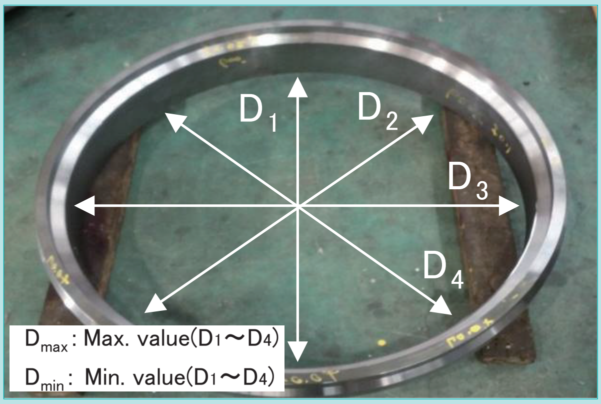

Fig. 6 Measurement Position of Roundness

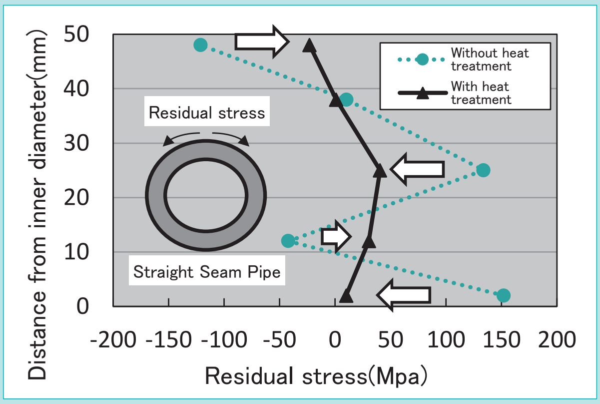

Fig. 7 Stress Relief by Annealing

4-2 New structure of mechanical joint having performance equivalent to conventional product

4.2.1 Thinning of the groove face

Since a rapid temperature change occurs on the groove section, stress concentration occurs and it is easy to fracture (Figure 8). Therefore, the thickness of the conventional mechanical joint is designed with a stress concentration factor of 1.25. In this development, the curvature of the groove is changed in order to relieve the local stress concentration. In this case, the optimum radius of curvature was determined by repeated numerical analysis.

In addition, from the results of repeated experiments and analyses, it was found that the local deformation of the Pin joint (inserting side) was larger than that of the Box joint (accepting side) of the mechanical joint.

Therefore, the local load of the Pin joint was reduced by changing the position of the groove of the Load-transfer key.

These structural changes made it possible to design the thickness of the groove section with a stress concentration factor of 1.1.

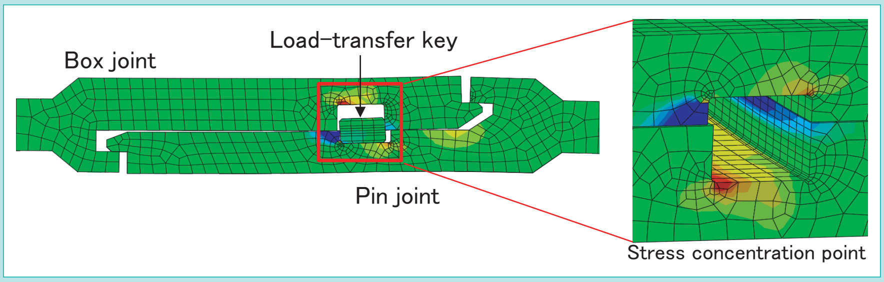

Fig. 8 Stress Concentration Zone of a Mechanical Joint

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4.2.2 Thinning of Load-transfer key

Since the Load-transfer key is embedded in the mechanical joint, the thickness of the entire mechanical joint is reduced by reducing the thickness of the Load- transfer key. The thickness of the Load-transfer key depends on the extent to which the contact area (Hereinafter referred to as "bearing area".) between the joint body and the Load-transfer key is required.

However, there has been no knowledge to determine how much bearing area is sufficient for conventional mechanical joints. Therefore, it was designed based on the past practice.

Thus, an element test simulating the load transmission part was repeatedly carried out, and the mechanism of bearing failure was clarified based on the element test results and numerical analysis results (Fig. 9). As a result of reviewing the bearing area, it was determined that it was possible to change the thickness of the Load-transfer key to 0.8 times the conventional thickness.

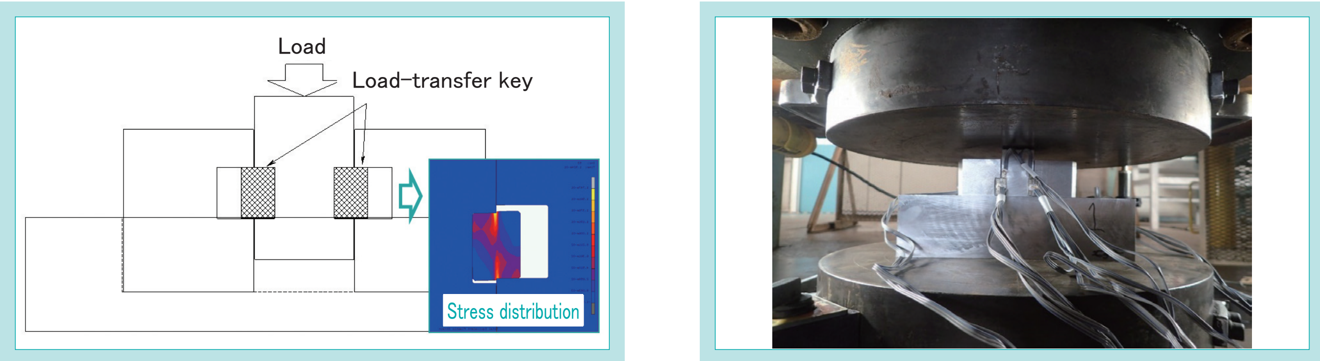

Fig. 9 Bearing Pressure Test of the Load Transfer Key

4-3 Performance of New Mechanical Joint

The mechanical joint designed to be lightweight was manufactured using straight seam pipe and its performance was evaluated. In this case, the mechanical joint is required to have the same or higher performance as the steel pipe pile and steel pipe sheet pile body.

4.3.1 Performance of Mechanical Joints against Bending Loads

4-point bending test was conducted to compare the bending strength of the mechanical joint part with that of the steel pipe pile (Fig. 10).

As a result of the bending test, the bending load over the fracture load of the main part of steel pipe pile was loaded though, the mechanical joint was found to be sound without any deformation or damage (Fig. 11).

Therefore, it was confirmed that the new mechanical joint has the same or higher bending strength as the main part of steel pipe pile.

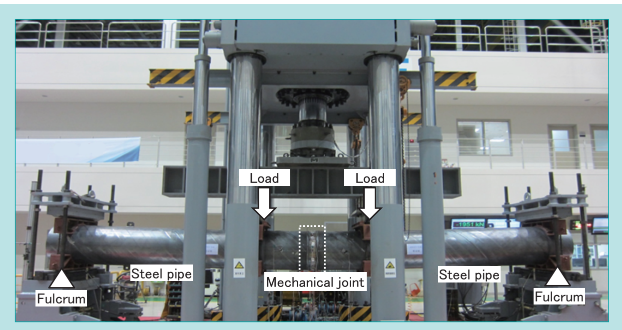

Fig. 10 Four Point Bending Test of Mechanical Joint(1)

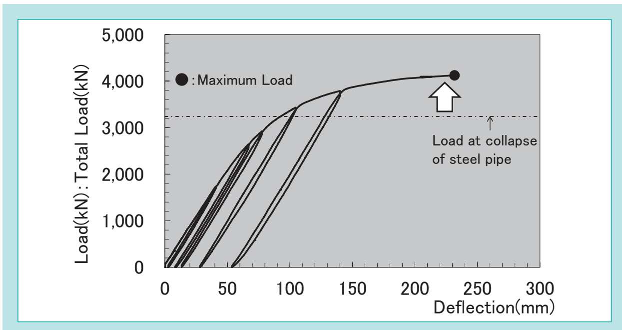

Fig. 11 Four Point Bending Test of Mechanical Joint(2)

4.3.2 Performance of mechanical joints against the impact load under construction

A specialized construction machine, such as a hydraulic hammer, is used for driving steel pipe piles and steel pipe sheet piles at construction sites.

Steel pipe piles and steel pipe sheet piles are driven into the ground by the impact, and a large impact load is applied repeatedly. So we checked whether the mechanical joints could withstand such impact loads. Specifically, an experiment was conducted in which the impact load (Maximum energy: 282 kJ) of a hydraulic hammer was repeatedly applied to a steel pipe pile joined by a mechanical joint in an actual size (Fig. 12).

More than 2,000 impacts were applied, which was much more than the number of impacts applied in normal construction, and the steel pipe pile was destroyed, but the mechanical joint was sound (Fig. 13),

As a result, it was confirmed that the strength of the new mechanical joint was equivalent to or higher than that of the main part of steel pipe pile.

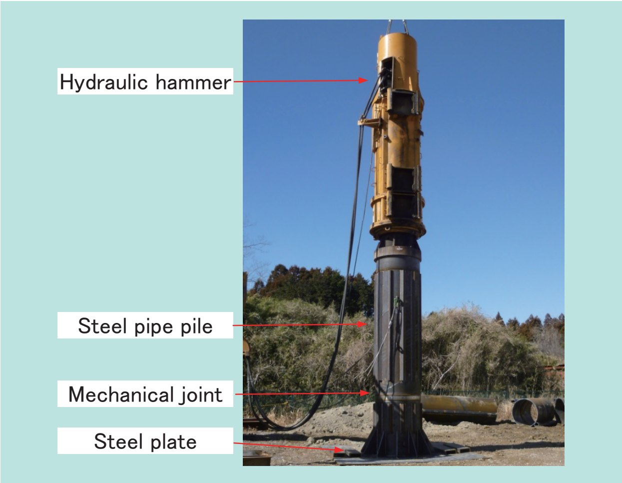

Fig. 12 Repeat Impact Test with a Hydraulic Hammer

Fig. 13 Mechanical Joint After a Repeat Impact Test

4-4 Improvement of Removal Function under Construction

In the construction of steel pipe pile and steel pipe sheet pile, it is necessary to remove the mechanical joint when any trouble occurs under the construction (For example, when construction is not completed within the specified time due to night work.). In recent years, there has been a particularly growing need for this removal function. However, in case of the conventional product, the set bolt for taking in and out the Load-transfer key is damaged by the impact force in constructing the steel pipe pile and steel pipe sheet pile, and the Load-transfer key cannot be pulled back to the inside of the Box joint. Therefore, in order to prevent the impulsive force at the time of installation from being transmitted to the set bolt, the set bolt was changed to a structure that does not mesh with the Load-transfer key (Fig. 14).

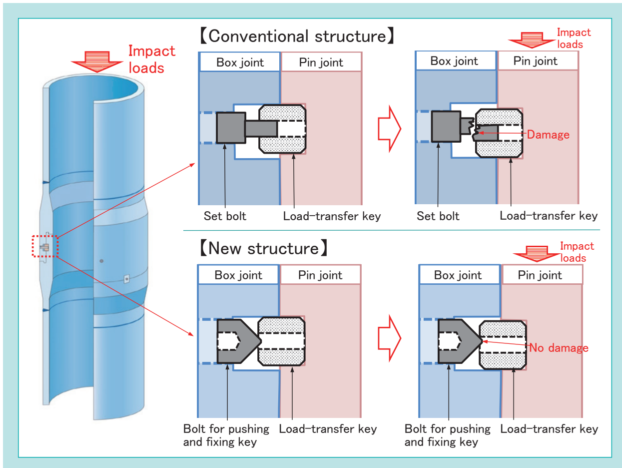

Fig. 14 Improvement of the Fixing Method

5. Conclusion

The development of mechanical joint (Laqnican Joint) began in 2000.

The first product, "Flat Type" was put on the market in 2002. Since then, minor changes were made to the "(Load-transfer key) Single Type " in 2006 and the "Step Type (old style)" in 2011, and at present, a new mechanical joint (Laqnican Joint Step Type) made of high-strength straight seam pipe is on the market.

In the development of this new mechanical joint, we succeeded in commercializing straight seam pipe for the first time in the industry, and achieved the target cost reduction rate of 50%. As a result, we were able to offer products that were about 60〜70% cheaper than in 2002 to the market.

In addition, in order to facilitate the adoption of new mechanical joint in public works projects, we received technical certification from a public certification body and obtained certification in Japan.

Furthermore, the first use of mechanical joints in overseas projects (Papua New Guinea) has paved the way for contributing to overseas infrastructure development.

In particular, the working environment in developing countries is not as good as that in Japan, and it is expected that mechanical joint can contribute to the improvement in those countries.

Contribution of SDGs to Target

8.8 Promoting a Safe and Secure Working Environment	Contributing to the Promotion of a Safe and Secure Working Environment by Improving Workability
9.a Promoting infrastructure development in developing countries	Contributing to the development of roads, railways and other infrastructure in more than 15 countries
11.5 Reducing the number of fatalities and victims of disasters and reducing economic losses	Contributing to the protection of human lives from floods and earthquakes in more than 15 countries