# Completion of an Optical Fiber Composite 500-kV DC Submarine OF Cable Project

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**ABSTRACT** A construction project of a DC submarine cable, to be known as Anan-Kihoku DC Trunk Line, has been under way to link the electric power grids between Kansai and Shikoku. This submarine cable line is designed to have a capacity of 2800 MW on one bipolar circuit of 500 kV DC with return conductor, requiring a cable system with a current capacity of 2800 A per line --the greatest submarine DC cable in the world. The cable was developed jointly by Kansai Electric, Electric Power Development, and four major cable manufacturers in Japan; and four lengths of the cables, each 50 km long, were manufactured by the cable manufacturers respectively, spending approximately two years. From April to December of 1998, the cables were laid and buried, one by one, using a cable laying ship and a laying and burying machine newly developed. Subsequently, connected with land cables, they satisfactorily underwent DC high-voltage tests at -700 kV in August 1999. They are scheduled to be in operation in July 2000, after a series of power grid linking tests. Furukawa Electric has supplied a length to be used as the main cable of 2nd circuit.

## 1. INTRODUCTION

Anan-Kihoku DC Trunk Line, with a cable section of 48.9 km and an over-head section of 50.9 km --totaling 99.8 km-- has been constructed to link the electric power grids between Kansai and Shikoku.

In this line, 500-kV DC submarine cables, having a length of 46.5 km each and the greatest capacity in the world, are used in the cable section. See Figure 1 and Table 1.

The cable was developed jointly by Kansai Electric, Electric Power Development, and four major cable manufacturers in Japan headed by Furukawa Electric; and four lengths of the cables, each 50 km long, were manufactured by the cable manufacturers respectively, spending approximately two years. In terms of installation work, the cable was planned to be buried for its entire length, considering that Kii Strait where the cable was installed had much sea traffic and that the cable was susceptible to possible damages due to dragnets of trawl fishery in prevalence in the sea area. In addition, in an effort to improve the positional accuracy of laying and to extensively reduce construction period, a cable laying ship and a cable laying and burying machine of new development were employed.

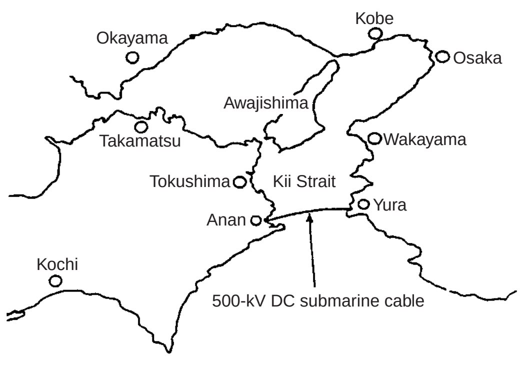


**Figure 1 Cable route**

**Table 1 Outline of the cable system**

| | |
|---|---|
| Transmission capacity | 2800 MW |
| Rated voltage | DC ±500 kV<br>(to be operated at ±250 kV in the beginning) |
| Transmission system | One bipolar circuit with return conductor |
| Rated current | 2800 A |
| Number of cables | 4 (2 main cables and 2 return cables) |
| Section length | 48.9 km (46.5 km undersea, 2.4 km on land) |
| Maximum route depth | 75 m in water |

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This report outlines the manufacture, installation, and DC high-voltage test of the 500-kV DC submarine OF (oil-filled) cable having the greatest capacity in the world.

## 2. CABLE

### 2.1 Structure of Cable

Since the cable is required to have a current capacity of 2800 A per line at 500 kV DC, it was decided to employ an OF cable for its high permissible conductor temperature and high reliability based on an established track record of long time. If conventional kraft paper were used for insulation, however, the insulation layer would be of great thickness with poor heat dissipation making the cable size far exceed the manufacturing capabilities. Accordingly, polypropylene laminated paper (PPLP) was selected for insulation for its excellent electrical properties so as to reduce the insulation thickness.

Furthermore, this submarine cable integrates 12 optical fiber units for information transmission, temperature sensing, mechanical damage sensing, and communication during maintenance work, in addition to sensing wires (polyethylene insulated copper wire) for the purpose of searching the buried location of the cable. See Figures 2 and 3 and Photo 1.

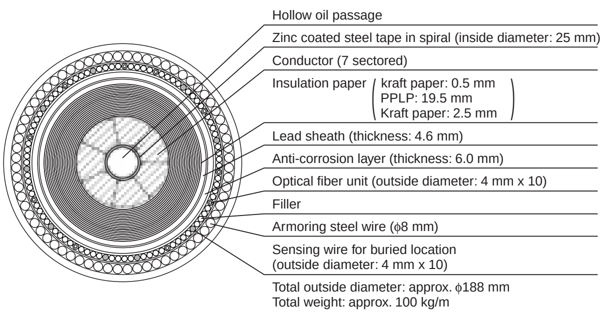


**Figure 2 Structure of optical fiber composite submarine OF cable**

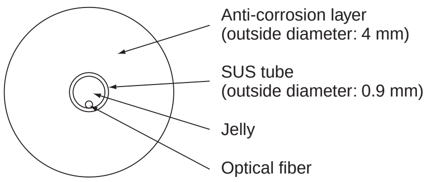


**Figure 3 Structure of optical fiber unit**

**Photo 1 Appearance of the submarine cable**

### 2.2 Manufacturing of Cable

Furukawa Electric began manufacturing the cable in June 1996, and successfully completed the manufacturing in June 1998 by jointing two lengths of the cable, each about 25 km long, at the factory.

The major manufacturing processes consisted of: manufacturing of conductor, insulation paper wrapping, drying, oil impregnation, lead sheathing, reinforcing by winding stainless steel tape, anti-corrosion layer sheathing, and steel wire armoring accompanied by optical fiber units integration.

In the manufacturing process, the cable core consisting of conductor with PPLP insulation was coiled in a large vessel about 20 m in diameter for drying and oil impregnation. The vessel was evacuated of air to remove gases and water vapor contained in the insulation layer, while the cable core was heated to a controlled temperature by current loading on the conductor and steaming on the vessel wall. 72 temperature zones were set up on the vessel wall and each zone was automatically temperature controlled based on a computer simulation to effect optimum heating, so that the entire length of such a long cable was uniformly heated. The entire volume of the vessel was filled with degasified insulation oil, then it was pressurized to carry out oil impregnation. During drying and oil impregnation, the equilibrium vapor pressure and static capacitance in the cable were monitored so as to grasp accurately the drying and oil impregnation conditions of the multi-layered coil of the cable core. See Photo 2.

In the lead sheathing process, the cable core was introduced from the oil impregnation vessel to the lead-sheathing machine through a guide pipe filled with insulation oil, and lead sheath was applied. The lead sheath was verified to be flawless for its entire length using an ultrasonic flaw-detection apparatus.

In the armoring process, 12 optical fiber units and polyethylene insulated copper wires for buried location detec-

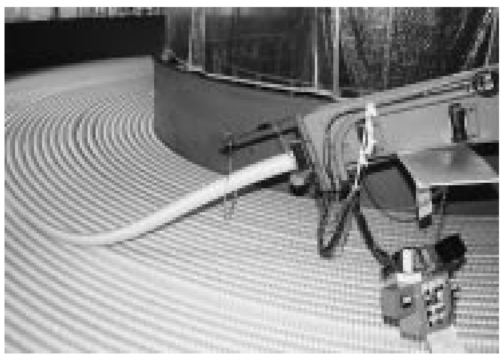

**Photo 2 Storing the cable core into a large vessel for drying and oil impregnation**

tion were stranded under the steel wire armor layer. The completed cable of about 50 km in length and about 5000 tons in weight was taken up on a large turn table 30 m in diameter and 6000 tons in capacity. In terms of optical fiber, all fiber units were monitored all the time for their transmission loss change, thus confirming that they were free of any performance change.

### 2.3 Factory Joint

Factory joint (FJ) was developed to meet the target specifications described below.

(a) To have almost equal electrical performance as that for the cable

(b) To show no degradation against the mechanical forces to be encountered

Thus, the FJ was designed to have a structure as close as that of the cable, so that the FJs were provided with the diameter and bending stiffness almost equivalent to that of the cable. Figure 4 shows the structure of FJ and below are given the procedures of manufacturing.

(1) Conductor jointing

Seven segments of the conductor were respectively jointed by TIG (Tungsten Inert Gas) welding. In the conductor welding, the cable portions on both ends of the FJ were made to freeze so as to prevent flow out of insulation oil and gas permeation to the cable.

(2) Insulation layer

Insulation building-up was carried out in a dehumidified room, by winding insulation paper of the same quality, thickness, and width as for the cable insulation until the outer diameter became equal to that of the cable.

(3) Lead sheathing

Single layer lead sheath was employed to make the outer diameter as close to that of the cable as possible and ultrasonic inspection was applied to confirm the soundness of sheath welds.

(4) Reinforcement layer

Reinforcement was applied in the longitudinal and lateral directions so as to relieve the stress on the lead sheath welds.

(5) Anti-corrosive layer

PE tape molding was used to finish the FJ, making the difference between the diameters of cable and FJ as small as possible.

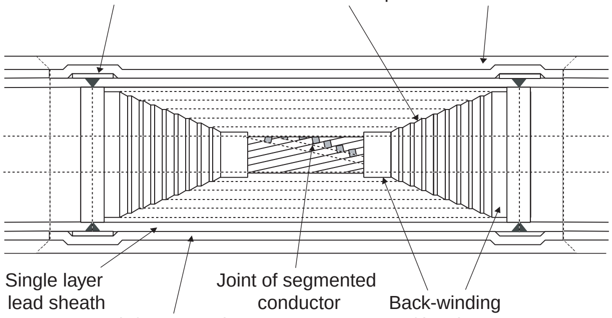


**Figure 4 Structure of factory joint**

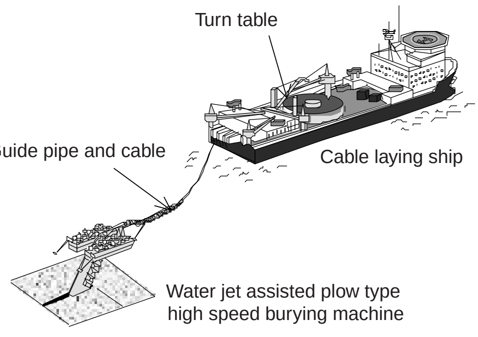


**Figure 5 Continuous laying and burying method**

## 3. CABLE LAYING WORK

### 3.1 Outline of Cable Laying Work

3.1.1 Laying and Burying Method in the Strait

In the cable laying work in the strait, the continuous laying and burying method was employed as shown in Figure 5, in which the cable was continuously laid and buried as it was paid off. The position of the buried cable was simultaneously monitored throughout the laying process, using GPS (Global Positioning System) and sonar.

It was estimated to take about two weeks to lay the cable across the strait, if a conventional burying machine of water jet type were used to bury the cable to a depth of 2~3 meters. Accordingly, the authors jointly developed a water jet assisted plow type burying machine, planning to cross the strait in two days including nights. See Photo 3 and Table 2.

**Photo 3 Water jet assisted plow type burying machine**

**Table 2 Outline of specifications for water jet assisted plow type burying machine**

| Item | Specifications |
|---|---|
| Excavating method | Water jet assisted plow type excavation<br>Number of plows: 6 |
| Excavation depth | 0~3.3 m (adjustable) |
| Dimensions | Length: 13.5 m, Width: 8.2 m, Height: 7.1 m |
| Weight | 105 tons in air; 31~87 tons in water |

A cable laying ship named Giulio Verne, which belongs to Pirelli in Italy, was employed. The ship was equipped with a turntable that enabled loading and laying of such a long and heavy cable of 50 km in length and 5000 tons in weight and was capable of towing the newly developed burying machine.

3.1.2 Laying and Burying Method in Tachibana Bay

On the Tokushima side, it was impossible for the cable laying ship to approach a shallow sea extending 5 km in Tachibana Bay. The cable was transshipped, therefore, from the cable laying ship to a barge at the entrance of the bay as shown in Figure 6, and was subsequently laid and buried continuously to a depth of 2~3 meters using the burying machine.

Tachibana Bay is dotted with five rocky spots in the seabed. A rock trencher shown in Photo 4 and Table 3 was used to trench the rocky spots prior to cable laying. Subsequently, each length of the cable was laid in the trench about 1 km in length using the burying machine towed by the barge.

During the cable laying, in order to lead the burying machine along the excavated trench, the position of the barge and the burying machine was precisely measured by laser light survey and the location of the trench ahead of the burying machine was monitored by sonar.

3.1.3 Laying and Burying Method near the Seacoast

Near the landing point off the seacoast of Wakayama, it was impracticable to obtain a sea depth sufficient for cable laying by the cable laying ship. Therefore, post-lay burying method using the burying machine was employed, and at both ends of the sector, the cable was buried manually by divers.

On the coast of Tokushima, manual burying was also carried out at the transshipment point and at the landing point where the burying machine was not usable. After the cable laying, sand was supplemented to the trench in the rocky spots and the place of manual burying, and the seabed was restored by leveling.

The cable laying and burying work described above gave satisfactory results, i.e., the cable burying depth satisfied the specification as shown in Figure 7; and the cable laying accuracy with respect to the planned route was ±5 m and ±1 m for the cable laying ship and the barge, respectively.

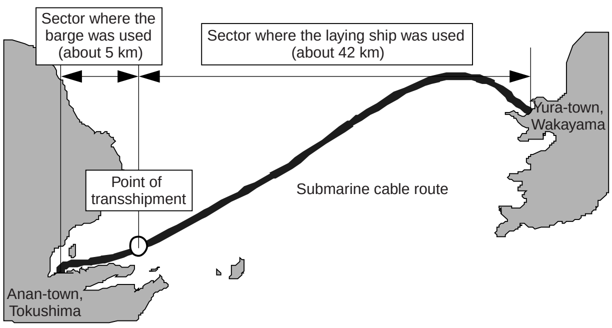


**Figure 6 Cable route across Kii Strait**

### 3.2 Work Schedule

Furukawa's cable was laid third according to the timetable shown in Table 4. The cable laying ship was made to berth in the base (Kobe harbor) after cable loading until the beginning of laying preparation so as to avoid the risks of laying work during the typhoon season. Throughout this period, however, we regularly checked and monitored the cables.

## 4. COMMISSIONING TEST

The submarine cables laid during the period of April to October in 1998 were subsequently jointed with the land cables; and in August 1999, a DC high-voltage test of -700 kV x 15 min (CIGRE recommendations) was carried out, confirming no abnormalities in the insulation performance.

## 5. CONCLUSION

In this world-class construction project of an optical fiber composite 500-kV DC submarine cable system, long lengths of the cable were manufactured spending about two years, laid during the period of April to October in 1998, jointed with the land cables, and satisfactorily passed a DC high-voltage test of -700 kV in August 1999, confirming no abnormalities in the insulation performance existed. The cable system is scheduled to be in service in July 2000, after undergoing the tests of electric power grids linkage.

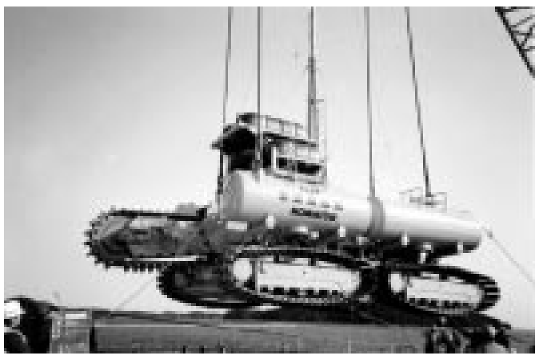

**Photo 4 Rock trencher**

**Table 3 Outline of specifications for rock trencher**

| Item | Specifications |
|---|---|
| Excavating method | Drum cutter for seabed leveling<br>Chain cutter for trenching |
| Propulsion | Self-propulsion |
| Excavating depth | 0~2.2 m (adjustable) |
| Excavating width | 0.65 m |
| Dimensions | Length: 11.5 m, Width: 5.5 m, Height: 3.4 m |
| Weight | 54 tons in air; 14~38 tons in water |

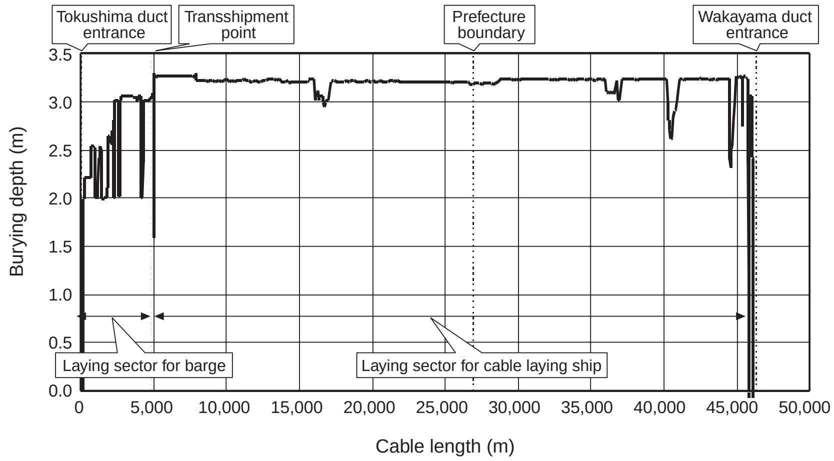


**Figure 7 Cable laying depth record of the Furukawa's work**

**Table 4 Record of laying work of Furukawa's cable**

| Content of work | | Date |
|---|---|---|
| Cable loading on board | Start | July 3 |
| | End | July 13 |
| Preparation for laying (Transshiment) | Start | October 3 |
| | End | October 5 |
| Laying by cable laying ship including landing | Start | October 7 |
| | End | October 12 |
| Laying by barge including landing | Start | October 6 |
| | End | October 24 |
| Post-lay burying on the Tokushima side | Start | October 25 |
| | End | October 28 |
| Post-lay burying on the Wakayama side | Start | October 25 |
| | End | October 28 |

It is our hope that many new technologies that have been verified and put into practical use during the course of this project contribute a great deal to the development of power transmission technology.

The successful accomplishment of this project is certainly brought about by the cooperation and guidance of many people concerned. In closing, we wish to renew our deep gratitude to them.

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