Completion of Submarine Cable Lines Combining Low Environmental Impact with Low Cost

*by Munehiro Furugen *, Yukio Noha *, Hideya Maekado *, Chihiro Yokoyama *2, Yukio Koshiishi *2, Shigeru Ebashi *2, Kunio Iwasaki *3, Takashi Kijima *3, Takumi Yamaguchi *4 and Hiroshi Kaizu *4*

ABSTRACT In a program to provide submarine cable lines having low environmental impact, Furukawa Electric has designed and commenced construction of the Hisamatsu-Irabu Line for Okinawa Electric Power (OEPCO) in May, 2000, and of the Niijima-Shikinejima Line for Tokyo Electric Power (TEPCO) in June of the same year. In the two projects a need for reduced construction cost was combined with a requirement for methods that did not damage coral reefs and submerged rocks used for the farming of "ise-ebi" crayfish. This entailed taking advantage of Furukawa Electric's comprehensive capabilities, from cable manufacture to cable laying. This total design capacity, covering everything from cable prototyping and design through cable laying design has made possible the construction of submarine cables that have minimal environmental impact.

1. 22-kV COMPOUND ARMORED SUBMARINE CABLE LINKING MIYAKOJIMA AND IRABUJIMA

1.1 Introduction

In May, 2000 a 22-kV submarine cable was laid in Okinawa Prefecture, connecting Hisamatsu on the island of Miyakojima with the island of Irabujima. The cable was of a newly developed type designated WCLWWA 3×100 mm^2 submarine cable (cross-linked polyethylene insulated cable with double armor and lead jacket for water exclusion), and the compound armor consisted of high-density polyethylene-sheathed FRP for the first layer and galvanized steel wire for the second layer. This newly developed cable offers improved long-term reliability--something that posed a serious problem in the submarine cables now in use--by providing the conductors with a lead water-exclusion layer, and employs a non-metallic material--fiberglass-reinforced plastic (FRP) serving--thereby protecting the sheath against electrical corrosion. The development work on this submarine cable was carried out jointly with OEPCO.

* The Okinawa Electric Power Co., Inc.
*2 Tokyo Electric Power Co.
*3 Technology Development Dept., Electric Wire and Equipment Div.
*4 Ocean Project Team, Electric Power Engineering Dept.

1.2 Problems with Cables Now in Use

1.2.1 Results of a Survey of Installed Cables

At present, OEPCO operates 29 submarine cable lines with a total length of 143.7 km. The lines lie in the Pacific Ocean and South China Sea subject to swift-flowing currents, and nearly all the areas where depths are less that 30 meters constitute the habitat of protected corals. Thus with few exceptions it is impossible to bury the cables.

Since submarine cables are frequently laid on this sort of route, damage to steel armor wire is particularly severe, and under certain circumstances damage could even extend to the insulation, reducing the service life of con-

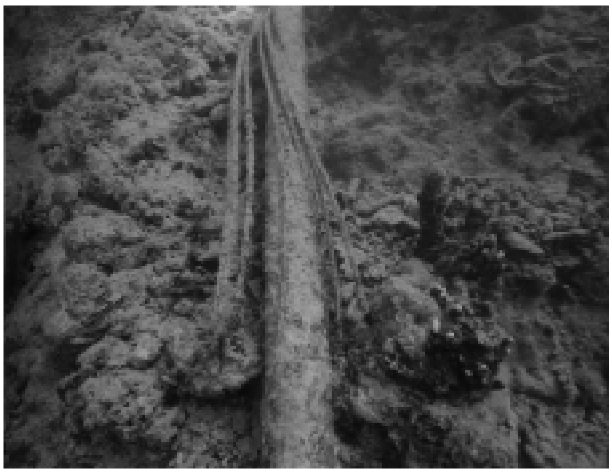

Photo 1 Submarine cable laid 28 years ago.

ventional submarine cables to the neighborhood of 20 years. Photo 1 shows the condition of a typical cable. This cable was laid 28 years ago, and there are places where the steel armor wire has frayed and parted so that on routes where the cable is lying on the seabed there is a chance that insulation faults could occur. And since the frayed ends of the steel armor wires are needle-sharp, published studies have long shown that the problem is not merely that of mechanical friction wear but of electrical corrosion.

Thus in an effort to improve the long-term reliability of submarine cables, a field survey was conducted to determine the extent of damage to the armor wire and find means of upgrading cable structure.

The field survey made use of data from regular inspections conducted every five years by OEPCO. Typical results are shown in Table 1.

By means of this survey it was confirmed that damage to the plastic yarn serving was sustained about 10 years after the cable was laid, after which corrosion of the steel armor wire began, and after a further five years breakage of armor wires began to occur. This is attributed to the fact that the functioning of the armor, which has been protected against external damage, deteriorates after about 10 years, making it possible for the cable insulation to be damaged during the dropping of anchors, or the heavy seas caused by typhoons, etc.

1.2.2 Damage to Steel Armor Wire

As was noted above, damage to the steel armor wire is attributed to electrical corrosion. Reference to the existing literature [1] suggests the following causes of electrical corrosion:

Table 1 Damage to steel armor wires of cables installed in Okinawa.

	Hisamatsu-Irabu #2	Bisezaki-Ie #2	Ishigaki-Taketomi #2
Years in service	27	19	16
Length	5.0 km	6.8 km	4.6 km
Max. water depth	14 m	92 m	33 m
Tidal current speed	1.5 knots	1.6 knots	0.6 knots
Condition of armor	Major damage to steel wire	Several steel wires damaged	Steel wires exposed

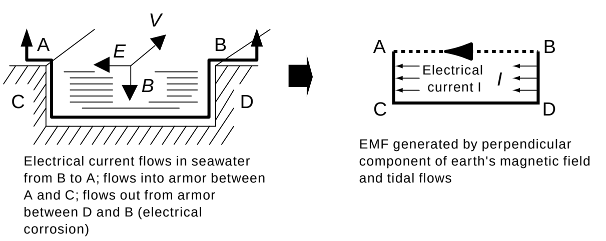

Figure 1 Schema of electrical corrosion of steel wire armor due to tidal flow EMF.

(1) EMF generated by tidal flows: This is due to the EMF generated by the earth's magnetic field and tidal flows and electrical current flows into and out of the armor wire near points where there are changes in flow velocity.

(2) Concentration cell effect: When the cable passes through areas of differing seabed formation or temperature, a current flows between two points on the armor wire that have differing potentials

(3) Differential aeration cell effect: This is an effect by which portions with an insufficient supply of oxygen act as an anode, so that parts of the armor wire adjacent or in contact are comparatively prone to corrosion.

(4) Leakage current from DC railway lines on land: Leakage current from electrified railway lines flows out of and into submarine cables.

(5) Ground current: Stray current flows out of and into the armor wire causing electrical corrosion.

Of these, it is considered that the main cause of the electrical corrosion of the armor wire of submarine cables is EMF generated by the earth's magnetic field and tidal flows. Note that abrasion against stones on the seabed and physical abrasion due to the severe motion of gravel in seawater caused by wave action are thought to be factors in the localized occurrence of natural corrosion due to damage to the plastic yarn serving, electrical corrosion and localized cell action, these are probably necessary conditions for damage due to electrical corrosion.

To summarize what has been stated above, the cause of damage to the steel armor wire surveyed was a combination of electrical corrosion, natural corrosion and physical abrasion.

Designing Submarine Cables with a View to Long-Term Reliability

Based on the results of the survey of cables now in service, we considered how to design a submarine cable suited to the conditions in which it would be laid.

Following are the items that were considered to assure the long-term reliability of submarine cables, together with the conclusions arrived at.

(1) Power cable (insulation): To attain long-term reliability on the seabed, we decided on a lead-jacket water-exclusion structure that would make possible a completely waterproof structure for the power cable. Naturally the interfaces between the core and the insulation shield and the lead jacket were filled with a watertight compound, forming a watertight structure that would, insofar as possible, prevent the entry of seawater into the power conductor, even if it was parted by damage due to the dropping of anchors or other cause.

(2) Armor: electrical corrosion has been identified as the cause of damage to the armor, which should therefore be made of a material in which electrical corrosion does not occur. This makes it necessary to use insulation made of a non-metallic material to completely eliminate electrical corrosion. The performance demanded of the armor, however, requires a material

Table 2 Cable construction.

Item	Power cable	Communi-cation line
Conductor cross section (mm^2)	100 (watertight over total length)	3P×2
Conductor OD (mm)	12.0	1.8
Insulation thickness (mm)	7.0	0.8
Insulation OD (mm)	26.0	—
Insulation shield thickness (approx., mm)	1	—
Lead jacket for water-exclusion layer thickness (mm)	1.6	—
Sheath thickness (mm)	—	2.0
Semiconductive tape thickness (mm)	0.5	—
Core OD (mm)	32.3	—
Braiding OD (mm)	70	
Bedding thickness (mm)	2.0	
High-density PE clad FRP OD (mm)	6.5	
Bedding thickness (mm)	2.0	
Galvanized steel wire armor OD (mm)	8.0	
Plastic yarn serving anti-corrosion layer thickness (mm)	5	
Finished OD (approx., mm)	119	
Approx. weight (kg/km)	30390	

that has high strength, and suffers little damage from seawater over the long term, and when account is taken of the record of long-term service established in the field, the choice is naturally limited.

The results of this study suggested FRP as a material that had a long record of service in seawater. FRP is a material that satisfies these conditions, and it has a record of use as the armor material of Furukawa Electric's submarine cables [2)] for some 18 years. FRP can, however, have a wide range of constituents, each with different properties, and it goes without saying that before it can be put to use its properties must be subjected to the fullest evaluation.

1.3 Construction of the Newly-Developed Submarine Cable, and Test Results

Table 2 shows the construction of the 22 kV 3×100 mm^2 WCLWWA (1st layer FRP, 2nd layer steel wire armor). There is no particular problem in using FRP wire in the manufacturing process, and experience has shown that it can be handled in the same way as steel wire. For FRP, however, splicing technology is crucial in that, depending on the formation of the splice, the drop in tensile strength of the FRP wire may be greater than desired. The splicing method developed for use in this work involves crimping of a stainless steel sleeve, and is extremely convenient.

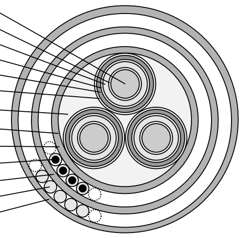

Figure 2 Cable cross-section.

Photo 2 Cable landing on Miyakojima.

1.4 Environment-Friendly Cable Laying Method

The cable developed in this work was laid between Hisamatsu on Miyakojima and the island of Irabujima--a distance of about 6,500 m. The method used to lay the cable was characterized by environment-friendly and protective measures designed to prevent, insofar as possible, any damage to the coral growing along the entire route.

The cable laying process started from landing on the Miyakojima end, and then proceeded toward Irabujima. The landing point on the Miyakojima end was a pylon, and on the Irabujima end a cable house. Laying was carried out by an anchoring technique that made possible precise navigation of the cable-laying barge. In this method, as can be seen in Figure 4, an anchoring wire was first deployed and then taken up by a winch mounted on the cable-laying barge, moving it forward and enabling the cable to be laid precisely along the pre-determined route.

The water along this route was comparatively shallow, raising fears that as typhoons approached, wave action would shift the cable over the seabed. This posed the danger of damage not only to the cable but also to the coral reefs in the vicinity, and made it necessary to lay the cable as directly as possible on the seabed to avoid, as much as possible, the bridging over declivities of the seabed that could result.

The cable laying process was guided over the entire length of the route by divers, so that laying in the gaps or natural troughs between the coral reefs was precise and bridging did not occur. This was a level of precision without parallel anywhere in the world, and it is thought that the elimination of cable bridging will be an effective means

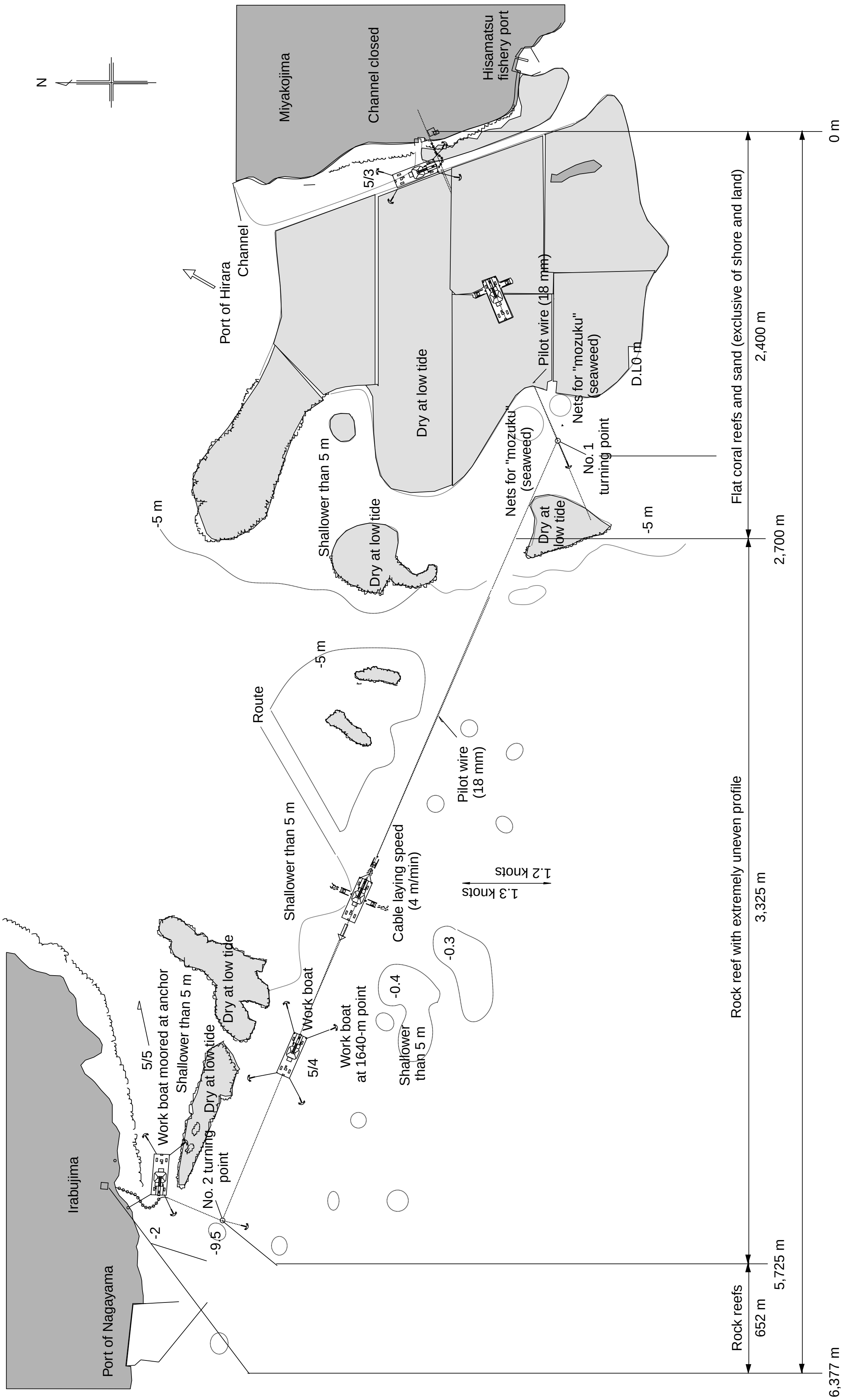

Figure 3 Route of submarine cable from Hisamatsu on Miyakojima to Irabujima.

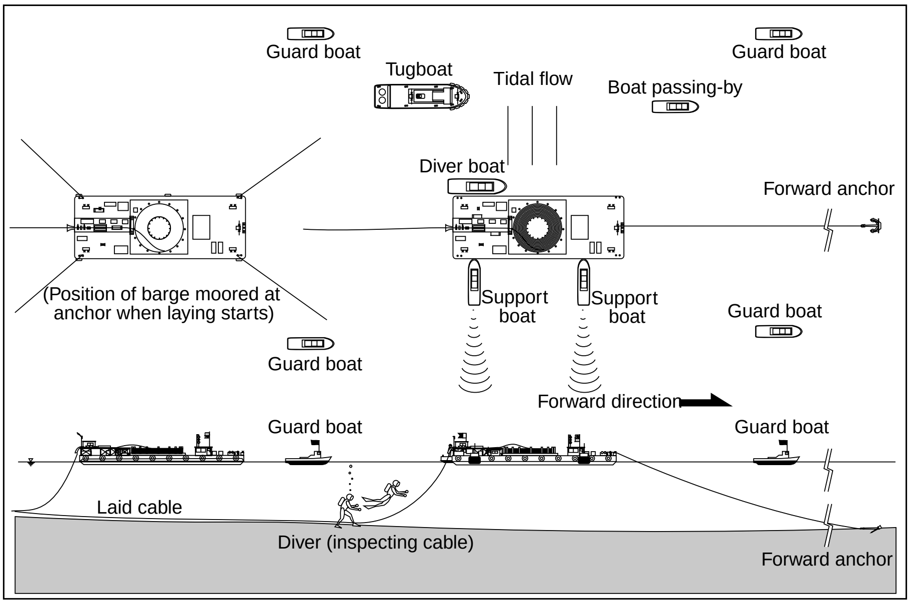

Figure 4 Cable laying by an anchoring method with diver support.

of extending cable life. The use of compound armoring for the cable and the consequent reduction in stiffness is advantageous in keeping the cable directly on the seabed.

1.5 Conclusion

In this work, with the objective of extending cable service life, a 22-kV submarine cable was developed having a compound armor (first armor layer: high-density polyethylene-sheathed FRP + galvanized steel wire), and it was laid using environment-friendly practices.

As a measure to counter electrical corrosion--a major problem for submarine cables--nonmetallic (FRP) wires were used in a portion of the armor, making it possible to improve the long-term reliability of the cable. The adoption for the armor of a compound structure using steel wire increased its mass when under water, thus eliminating the mechanical damage caused to coral cable by cable movement due to wave action along routes where the cable is not buried, and also damage to the cable itself.

2. 6.6-kV SUBMARINE CABLE LINKING NIIJIMA AND SHIKINEJIMA

2.1 Introduction

In June, 2000 a 6.6-kV WCLWA 3×60 mm^2 steel wire armored submarine cable (with single-layer armor, with cross-linked polyethylene insulation and lead jacket for water exclusion) was laid between the islands of Niijima and Shikinejima, which are part of Tokyo. The project was undertaken to satisfy increasing power demand on Shikinejima. Based on studies of cables now in service, Furukawa Electric was able to set forth clearly the cable construction, route, cable laying process and the functions required of the protective construction, along with proposed savings in overall costs, and we achieved a reduction in total construction cost.

2.2 General Description of Project

This project involved the laying of a submarine cable over a distance of approximately 4,242 m between Niijima and Shikinejima. On the cable route there are mounds of sand in mid-channel, but in the areas close to the two shores there are scattered rocks--not a desirable location for the laying of a submarine cable. Accordingly cables now in service have two-layer steel-wire armor, and in addition are provided with a protective pipe [3].

2.3 Design of Cable Laying Work

This expansion project was subject to the following requirement:

1) Lower construction cost,
2) High line reliability,
3) Minimization of environmental impact.

With specific reference to 3), the areas of submerged rocks near the landing shore were used for the farming of "ise-ebi" (crayfish), leading to strong representations being made by those in the local fishery industry.

Generally speaking, cables being laid over submerge rocks use the same specification for two-layer steel-wire armor adopted for cables now in service. When there is also a danger of damage due to boulders, etc. it is common to assure cable safety by the use of a cast iron protective pipe, or by crushing and removing the rock.

In the present case, however, it was decided, based on the study of cables now in service, that we would not be bound by the safety-first design concept grounded in past experience, but would select a cable with single-layer steel-wire armor.

Preparatory studies were carried out with great thoroughness, and in an effort to select a route where the cable would be naturally buried by tide-induced movement of the sand, we chose a meandering route that avoided submerged rocks, thereby cutting down the number of protective steel pipes.

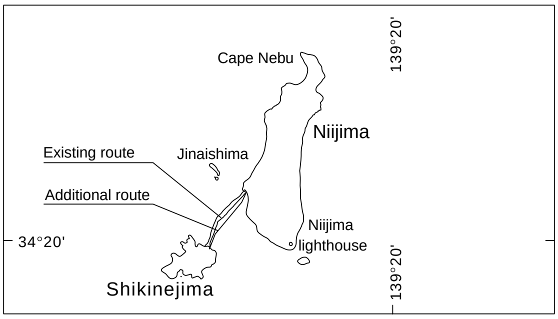

Figure 5 Route of submarine cable from Niijima to Shikinejima.

Table 3 Cable construction.

Item	Power cable
Conductor cross section (mm^2)	60
Conductor OD (mm)	9.3
Insulation thickness (mm)	5.0
Insulation OD (mm)	19.3
Insulation shield thickness (approx., mm)	0.6
Lead jacket for water exclusion layer thickness (mm)	1.5
Sheath thickness (mm)	—
Semiconductive tape thickness (mm)	0.25
Core OD (mm)	—
Braiding OD (mm)	58
Bedding thickness (mm)	2.0
Galvanized steel wire armor OD (mm)	8.0
Plastic yarn serving anti-corrosion layer thickness (mm)	3.5
Finished OD (approx., mm)	81
Approx. weight (kg/km)	17590

To assure that the cable was laid precisely along the proposed route, an anchoring technique like that used on the Miyakojima-Irabujima route was adopted, with guidance by divers provided throughout. This route guidance also led to a reevaluation of the structure of the armor, and the resulting adoption of single-layer steel-wire armor, was extremely effective, decreasing the rigidity of the cable.

As a result of these measures, it was possible to reduce the use of protective pipe and the crushing and removal of submerged rock to the minimum levels possible, realizing a saving in total construction cost of approximately 5%. The reduction in the crushing of submerged rock also made it possible to reduce the impact on marine life to minimum levels.

Photo 3 Cable landing on Niijima.

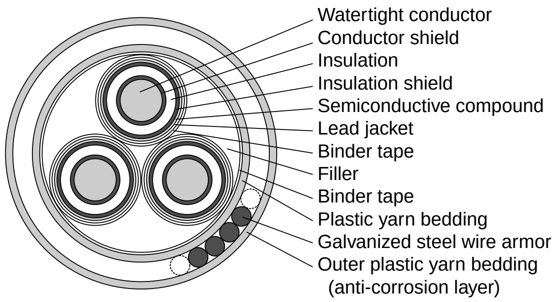

Figure 6 Cable cross-section.

2.4 Conclusion

In the project discussed here an optimal cable design was developed based on the experience of cables now in service, and reliability was achieved by the cable-laying design. In the future Furukawa Electric intends to make full use of its comprehensive capability in the design and laying of cables on a variety of submarine routes, grounded on a track record of laying more than 1.5 million kilometers of cable and the experience gained in the project described here, in proposing cable-laying techniques that are both cost effective and low in environment impact.

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