A Technical Report on the Advanced Real-time Earth Monitoring Network in the Area (ARENA)

Chapter 5: The Underwater System

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Contents

5.1 Introduction

In this chapter, technical requirements for the underwater system will be clearly specified (in **Section 5.2**), and the configuration of an observation node, main components of the underwater system and their reliability, installation and repair methods for the power branching unit (PBU) and node branching unit (NBU), and a system necessary to support construction and maintenance operations will be discussed. As the underwater system will comprise a wide range of components, discussions here will center on those that will have a major impact on the reliability of the system as a whole.

A typical observation node consists of a cluster of observation sensors, an underwater hub unit (UHU) that serves as a hub for these sensors, an NBU that provides an interface between the backbone cable and UHU, and a branching cable that connects the UHU to the NBU. Sensors may be deployed at a single location in a concentrated manner or distributed across multiple locations 10 to 20 km apart. The arrangement of these pieces of equipment and methods used to connect them together will greatly influence installation and repair methods. For this reason, the configuration of an observation node will be discussed in **Section 5.3**, where an optimum configuration is proposed.

The reliability of underwater equipment is an important technical issue in the development of a scientific underwater cable network. Repairing underwater equipment is a technical challenge which demands significant cost as well as considerable preparation and operation time. For this reason, equipment to be installed on the ocean floor is required to have high reliability. For example, optical underwater telecommunication cables have been designed to meet a reliability standard of only a few repair incidents over their design life of 25 years. However, to ensure such a high level of reliability, it is necessary to subject all components to rigorous reliability evaluation tests and quality control. For instance, underwater repeaters for underwater telecommunication cable systems use electronic components that meet a reliability standard of no more than several FITs, where 1 FIT is a failure rate of one in 10^9 hours = 114,155 years. Nevertheless, since such high-reliability components are limited in range and very expensive, it is unrealistic to expect a similar level of reliability from the components of the ARENA system. With the power supply and signal transmission systems, this issue can be tackled by enhancing redundancy and designing the system in such a way that it will be able to minimize the reach of effects in the event of a fault. In the case of underwater cables, pressure vessels, underwater mateable connectors and sealings, however, it is difficult to introduce redundancy, and their degradation would directly lead to a degradation of the system as a whole. In **Section 5.4**, therefore, existing technologies relating to the mechanically important components of the underwater system will be investigated to identify issues that need to be addressed. Pressure vessels will not be discussed here since the reliability of titanium or beryllium copper pressure vessels has already been established.

Construction and repair methods will be discussed covering the PBU and NBU (in **Section 5.5** and **5.6**).

Under the proposed scientific underwater cable network, it is envisaged to deploy sensors on the ocean floor up to 6000 m deep. To deploy observation instruments efficiently at such depths, however, a heavy- duty ROV system that are much larger than what have until now been the norm will be needed. From this viewpoint, a new ROV system will be proposed in **Section 5.7**.

5.2 Technical requirements for underwater system

The underwater system consists of underwater cables, PBUs, NBUs, UHUs and observation instruments (sensors). The followings are basic technical requirements for underwater system.

(1) Cost performance

To build a large-scale system through the deployment of large numbers of devises over a wide area, it is important to keep the costs of individual devises in check while ensuring a high reliability for the system as a whole.

(2) System reliability

(a) Robustness against faults

The system needs to be configured in such a way that the extents of effects of a single fault should be minimized.

(b) Reliability of key system

Since faults occurring in the key devices, particularly the backbone data transmission system and backbone power feeding system, will have far-reaching effects, they need to have a higher level of reliability than sensors, UHUs, etc.

(c) Evaluation of reliability

The reliability of underwater equipment needs to be evaluated as thoroughly as possible.

(3) Expandability

(a) System expandability

The system needs to be designed in such a way that it readily accommodates expansions, such as the addition of new sensors and enlargement of the cable network.

(b) Easily replaceable sensors

Since sensor technology advances rapidly, it is important to use the latest sensors as much as possible. In light of this, it makes more sense to place greater emphasis of the replaceability of failed sensors than requiring extremely high reliability from individual sensors. For this reason, underwater mateable connectors should be used for the connection of sensors to ensure easy replaceability.

(4) Construction and maintenance

(a) Construction using existing cable ship

Since the proposed cable network has a complex configuration, it will require some construction methods that have never been tried. In this regard, it is necessary to pay due regard to the weight and size of equipment to be installed and capabilities of existing cable ship and workboats, as well as time needed for operations.

(b) Maintenance without using cable ship

Cable ships are few in number and expensive to operate. It is therefore necessary to investigate the possibility of carrying out the replacement of sensors and repair of UHUs using a research ships or workboats.

5.3 Configuration of observation node

Figure 5-1 shows the basic configuration of an observation node. NBUs are inserted in the backbone cable at intervals of about 50 km. A branching cable is connected to each NBU, with a UHU attached to the other end. The role of the NBU is to branch power and signals off the backbone cable. The UHU serves as a hub for sensors, and allows other UHUs to be connected to it via extension cables. This configuration - akin to Ethernet - makes it possible to set up multiple observation points approximately within a 10 km radius of the NBU to deploy sensors. There are a few options in this configuration as shown in **Table 5-1**.

An NBU can be either with or without a built-in DC/DC converter for power supply. An NBU that does not have a built-in DC/DC converter physically branches a power feeding line and an optical fiber off the backbone cable and brings them to a UHU via a branching cable (**Figure 5-2**). In this case, assuming the constant current power feeding system, the power feeding line will have to have two or more conductors, but the incorporation of a multi-conductor high-voltage power cable will not be easy for reasons to be explained later. It is therefore desirable that a DC/DC converter be built into the NBU, with power supplied to the UHU at a low voltage.

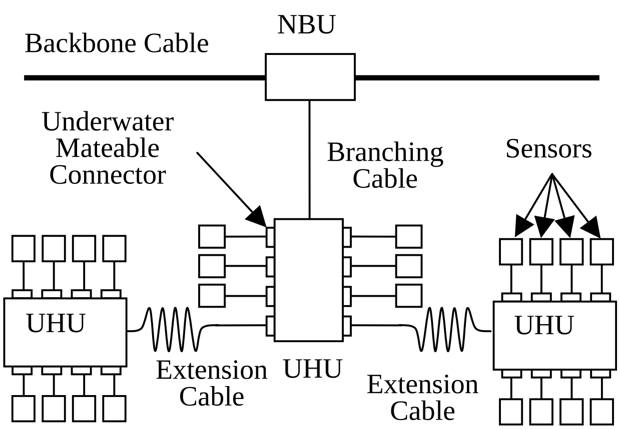

Figure 5-1 Basic Configuration of Observation Node

Theoretically, sensors can be directly connected to an NBU, although this is not the case with **Figure 5-1**. In this instance, an underwater mateable connector would have to be used for the NBU, thus reducing its reliability. Since an NBU cannot be repaired unless the power supply to the backbone cable is shut down, its failure will have a major impact on the system as a whole. Although underwater equipment to be inserted into the backbone cable is required to have high reliability, the long-term reliability of underwater mateable connectors has not been established. The use of underwater mateable connectors for NBUs, therefore, is contradictory to the above reliability requirement. Indeed,

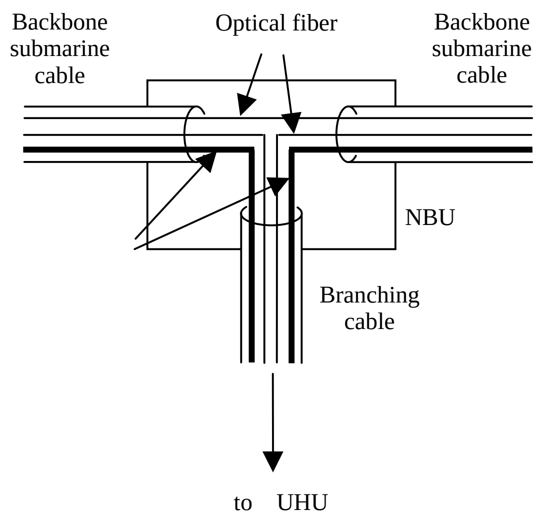

Figure 5-2 Configuration of Direct Branching Type

from the viewpoint of maintaining reliability, it is desirable to limit the functions of the NBU and keep its electronic circuit as simple as possible. For these reasons, it is not recommended to directly connect sensors to an NBU.

There are two means of connecting the backbone cable and a branching cable together: a feed-through and underwater connector. From the viewpoint of long-term reliability, feed-throughs are superior to underwater connectors that use o-rings. For this reason, feed-throughs are recommended as the means of cable branching.

The built-in power supply and data transmission equipment in an NBU are discussed in the **Chapter 3** and **Chapter 4** respectively.

It is also theoretically possible to connect multiple UHUs to an NBU. However, to do so would not only compromise the reliability of the NBU but also make it larger and cumbersome due to the use of multiple feed-throughs. It would also increase the number of DC/DC converters and other built-in devices, thus further reducing reliability. For these reasons, it is desirable that only a single UHU be connected to an NBU.

As options for the branching cable, the same optical underwater telecommunication cable as the one that is used as the backbone cable or a composite cable consisting of a multi-core power feeding line and plural optical fibers may be considered. The optical underwater telecommunication cable has a number of advantages including: simple construction and guaranteed high reliability; possibility of installation at and recovery from depths of up to 8000 m; resistance to high voltage; and low cost and well-established repair methods. However, its power feeding line has only one conductor, so that seawater must be used as the return path for the currents, giving rise to the need for close attention to the issues of ground electrodes and electrolytic corrosion.

A composite cable incorporating a multi-core power feeding line and optical fibers, on the other hand, can be kept small-size as long as the voltage is low, thus enabling its installation through direct payout from a cable reel. The control of the cable-laying route is also easy, while there is no need to worry about the issues of ground electrodes and electrolytic corrosion. Above all, this type of cable has already been used in the Off-Kushiro and other systems. However, it has its shortcomings. Firstly, a feed-through for the NBU that would suit a composite cable would have to be developed from scratch. Secondly, such a cable has never been installed at such great depths using a cable ship. Thirdly, repair techniques, including cable joining, would also have to be developed. For these reasons, it is necessary to continue conducting a comparative study on the basic structure of the branching cable.

Two methods of connecting a UHU to a branching cable may be considered. These are the use of a feed-through and that of an underwater mateable connector. Although the use of a feed-through was recommended for an NBU, this may not necessarily apply to a UHU. Namely, the use of a feed-through at both ends of branching cable would exclude a drum-based cable laying method such as the one used in the Off-Kushiro system. It would also lead to a difficulty in precisely controlling the cable laying route and UHU installation location and a complex construction method.

The use of an underwater mateable connector, on the other hand, would enable a precise control of the installation location of the UHU, although it would reduce reliability. On balance, it is desirable to use an underwater mateable connector for the connection between a branching cable and UHU.

Figure 5-3 shows the recommended configuration of an observation node arrived at through the above discussion. The NBU is equipped with a Ethernet switch and a DC/DC converter which supply low-voltage power to UHUs. Further study will be needed regarding the structure of the branching cable.

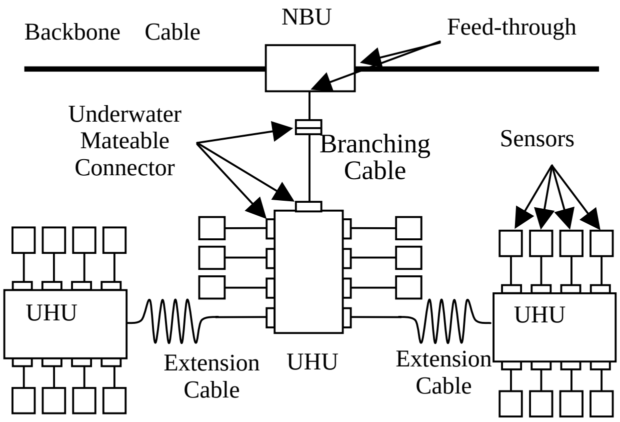

Figure 5-3 Recommended Configuration of Observation Node

Table 5-1 Options for Configuration of Observation Node

Item			Advantages/disadvantages
NBU			
	DC/DC converter		
		Built-in (recommended)	There is no need to develop a special high-voltage-proof branching cable incorporating multi-core power feeding lines.
		Non-built-in	An improvement in the reliability of the NBU. A special high-voltage-proof branching cable incorporating multi-core power lines is needed.
	Direct connection of sensors		
		No (recommended)	A reduction in the number of parts, which tends to increase reliability.
		Yes	A reduction in reliability due to the use of underwater mateable connectors, etc.
	Connection of branching cable		
		Feed-through (recommended)	High reliability
		Underwater connector	Ease of carrying out a large number of connections. Difficulty in verifying long-term reliability.
	Number of UHUs connected		
		One (recommended)	Connection of a single UHU. Simple construction, highly reliable and easy to repair.
		Two or more	Low reliability due to an increased number of internal parts, etc. Large size, complex and cumbersome to handle.
Branching cable (NBU-UHU)			
	Basic structure		
		Optical underwater telecommunication cable	Highly reliable, relatively inexpensive and easy to install. A joining technique already developed. The issues of ground electrodes necessitated by the lack of a return conductor and electrolytic corrosion need to be sorted out.
		Composite cable incorporating multi-core power feeding lines	The development of a composite cable incorporating a high-voltage multi-core power feeding line is difficult, although a low-voltage version is feasible. There is a need to develop a feed-through, joining technique, etc.
	Connection to UHU		
		Underwater connector (recommended)	Precise installation of the UHU is easy. The distance between the UHU and NBU can be reduced.
		Feed-through	High reliability. A distance at least 1.5 times the depth is needed between the UHU and NBU. There is a need for a high-strength branching cable.

5.4 Components of underwater system and reliability

Although a range of reliable existing technologies for underwater telecommunication cable systems can be adapted to the underwater system, such technologies alone are not enough to implement the system in view of expandability. However, new technologies are often unproven, and would therefore have to be thoroughly scrutinized in terms of reliability. For this reason, the reliability of these technologies will be examined in this section, focusing on underwater mateable connectors and o-rings.

5.4.1 Underwater mateable connectors

Underwater mateable connectors are an essential tool to connect NBUs, UHUs and observation instruments together, and their reliability is a critical factor in determining the reliability of the system as a whole. Although underwater mateable connectors have been used in some projects such as, VENUS and Off-Kushiro-Tokachi, their long-term reliability is far from guaranteed, given that they have been on the market for only four years. It is therefore necessary to verify their reliability, including evaluation methods, focusing on the following items:

(1) Long-term durability (corrosion due to leakage currents, evaluation of insulation degradation, and study of accelerated tests)

(2) Repeated mating and demating in turbid seawater (evaluation of mating and demating conditions under assumed manipulator handling, particularly insulation degradation and optical loss in the heavy turbid water with mud)

(3) Effects of vibration that may occur with cable connected (truck transportation and lowering/raising operations)

(4) Durability of cable sheath and tube against pressure-compensated oil

The specifications of underwater mateable connectors as released by their manufacturers.

5.4.2 O-rings

O-rings are sealing materials that are widely used for their ability to provide simple and compact sealing solutions. However, there are some questions about their long-term reliability due to the fact that they rely on the elasticity of material for their sealing performance. Nevertheless, the use of o-rings cannot be totally eliminated from underwater observation systems as they are unavoidable in some devices, including underwater connectors. This makes an evaluation of the reliability of o-rings an essential task. Besides, the establishment of the reliability of o-rings would lead to an expansion of their use, thus contributing to a simplification of the structural design of equipment.

(1) O-rings suitable for underwater use

Typical rubber materials used to make o-rings include nitrile rubber, fluoro rubber ("Viton"), silicone rubber, urethane rubber and ethylene-propylene rubber. **Table 5-2** shows the characteristics of these materials.

The type of rubber needs to be selected according to contact fluid, the environment and other conditions. Although all materials shown in the table tolerate exposure to fresh water or seawater, with the exception of urethane rubber, ethylene-propylene rubber is believed to be most suited for that kind of application.

Tale 5-2 O-ring Materials and Characteristics

Material	Characteristics
Nitrile rubber (NBR)	Most common / Mechanical strength: high / Compression set performance: good / Atmospheric corrosion resistance: poor
Fluoro rubber (FKM)	Heat resistance, atmospheric corrosion resistance and chemical resistance: very good / Compression set performance: very good / Low-temperature resistance: somewhat poor
Silicone rubber (MQ, etc.)	Heat resistance, low-temperature resistance and atmospheric corrosion resistance: very good / Mechanical strength: low / Gas permeability: high
Urethane rubber (AU, EU)	Mechanical strength: high / Chemical resistance and atmospheric corrosion resistance: poor
Ethylene-propylene rubber (EPM, EPDM)	Weather resistance: very good / Compression set performance: good / Atmospheric corrosion resistance: good / Oil resistance: poor

(2) Long-term reliability of o-rings and accelerated tests

O-rings get their sealing ability from the elastic force of rubber generated when it is compressed in a fitting groove (contact pressure). The main causes of leakage are inadequate contact pressure due to insufficient compression, insufficient elasticity, etc. and uneven contact surface due to scratching, corrosion, etc. The sealing performance of o-rings deteriorates with long-term continuous use due to loss of elasticity resulting from material degradation. This phenomenon needs to be further elucidated to establish the long-term reliability of o-rings.

There have been a few reports on the long-term reliability of o-rings used in the presence of air. **Figure 5-4**, log-log plots of the compression set of an o-ring against compression duration in days, is an example. The graph shows that o-rings are fit for long-term use at low temperatures, as long as material and the service environment are selected appropriately. Since the service life of o-rings is temperature-dependent, accelerated tests can be used.

In contrast, reports on the long-term use of o-rings in the presence of seawater are virtually nonexistent, despite the fact that there have been many instances of o-rings having been used for several years. Although seawater provides some advantages, such as the absence of ozone and ultraviolet radiation and low stable temperatures, it may accelerate material degradation due to chemical reaction with dissolved ions. For these reasons, it is problematic to use data obtained from tests conducted in the presence of air without further verification, giving rise to the need for new data. When pressure-compensated oil is used, the long-term durability of the o-ring concerned in the presence of that particular oil needs to be evaluated.

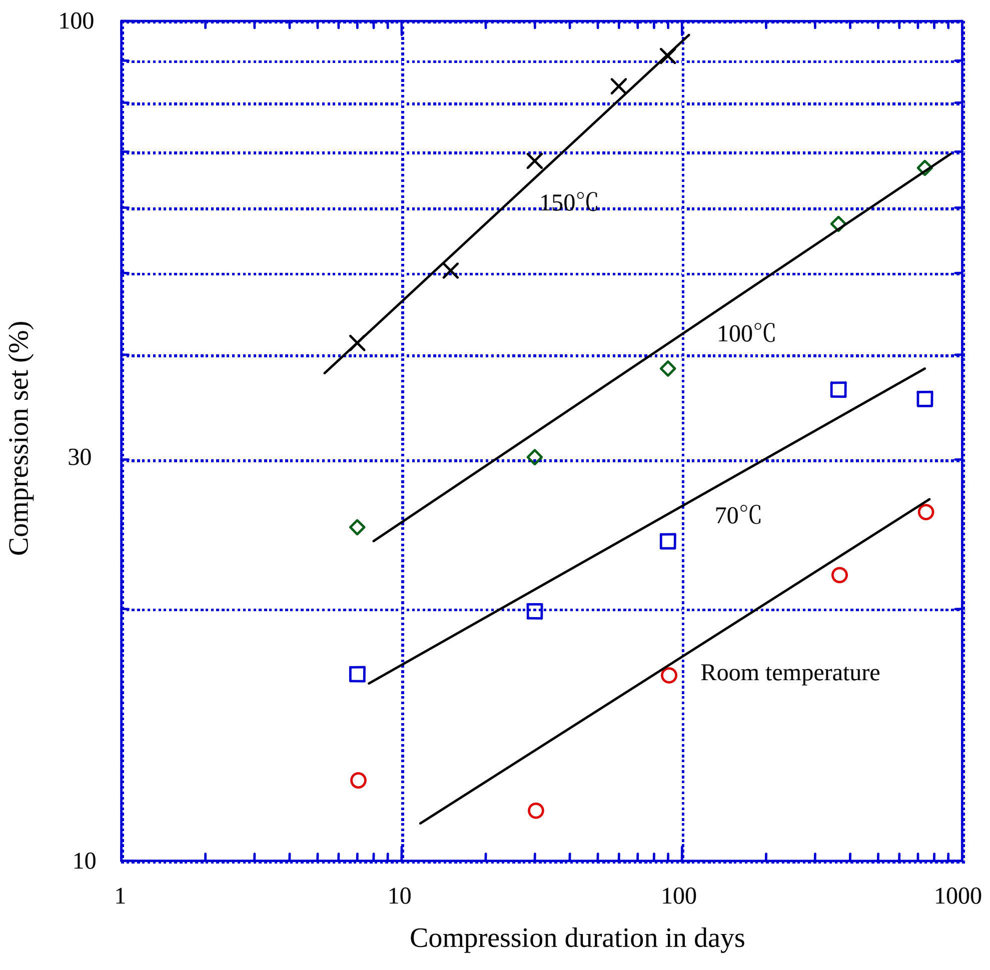

Figure 5-4 Example of Relationship between Compression Set and Compression Duration measured in Presence of Air

Source: Mitsubishi Cable Industries, Ltd.
The o-ring is made of ethylene-propylene rubber (2104-70) with a 5.33 mm cross-sectional diameter and 37.46 mm inside diameter. Based on experience, this material is believed to be fit for use as long as its compression set remains within 80%.

(3) Grease-related problems

Grease is used to reduce friction generated when fitting an o-ring into a groove and prevent twisting or biting.

Since grease could damage an o-ring depending on the combination of the grease and o-ring material, it is necessary to ensure compatibility with the o-ring material when selecting grease.

5.4.3 Other equipment

Apart from underwater mateable connectors and o-rings, the following issues need to be taken into consideration with regard to the reliability of the components of the underwater system:

(1) Electrolytic corrosion between dissimilar metals

When dissimilar metals are placed in proximity of each other, corrosion will take place even in the absence of electric contact. Although titanium alloy, a metal expected to be used as the main pressure housing material for underwater equipment, and beryllium copper, a metal possibly used for some cable couplings, are both highly corrosion resistant, there is no data on corrosion that may occur when they are used together. The simultaneous use of these two metals should therefore be investigated in terms of this type of corrosion. An investigation should also be made into corrosion between two titanium-based metals with different compositions that may take place when they are in contact with each other. The use of a dissimilar metal, including aluminum alloy, should be avoided.

(2) Underwater cable

The seawater resistance of the outer jacket of the underwater cable and, in the case of a fluid-filled underwater cable, the resistance of the tube and power line against pressure--compensated oil need to be examined.

(3) Underwater electrodes

When seawater is used as the return path for currents, underwater ground electrodes will have to be provided. Even if negative electrodes are made of corrosion resistant material, anodic reaction involving the housings of observation instruments, etc. may still occur due to stray currents. It is therefore necessary to study/evaluate electrode positions, the way in which stray currents flow, likelihood of the occurrence of electrolytic corrosion due to stray currents, and other issues.

(4) Crevice corrosion

Corrosion often occurs in minute gaps created along contact surfaces between metal and plastic, metal and rubber, and the like.

Methods to prevent crevice corrosion include the elimination of gaps and use of plastic, rubber or the like with a low water absorbability.

5.5 Construction methods

Roughly speaking, construction work to be undertaken under the ARENA project is divided into two categories: the installation of backbone cables, PBUs and NBUs using cable ships; and the installation of UHUs, extension cables and observation instruments using marine research ships and other vessels. Of the former, the installation of backbone cables can be carried out using existing construction techniques developed for underwater telecommunication cable systems. However, since the installation of NBUs to be deployed every 50 km and four-way underwater PBUs has never been done, an investigation will be made into their installation methods in this chapter.

5.5.1 Proposed NBU (underwater three-way) installation method

When examining an installation method, the shape and weight of the object to be installed are important considerations. However, since the shape and weight of the NBU is still being determined, an examination is to proceed assuming a similar size and weight to those of the branching unit developed under the VENUS project here. That branching unit is considered to be close to the limit size that can be handled using a current cable ship. The maximum water depth is about 6000 m.

Figure 5-5 shows a proposed NBU installation method.

The length of branching cable B is assumed to be about 1.5 times the water depth. The use of such length of a branching cable eliminates the need to retrieve the NBU when repairing a UHU and its associated underwater mateable connectors.

The installation of an NBU proceeds in the following manner. First, backbone cable A is laid, with its near end left in the water with a buoy attached to it. Next, branching cable B is laid, while the near end of backbone cable A is retrieved onto the vessel along with the buoy. Backbone cable C is then connected to the NBU, followed by the connection of backbone cable A and branching cable B to it.

Far end of branching cable B connected a protective frame. A portion of the cable has been wound into a coil and placed in a protective frame, by unwinding the coil and stretching it to a UHU, to which it is to be connected using an ROV.

When lowering the NBU off the ship, an auxiliary rope (not shown in **Figure 5-5**) is attached to backbone cable A to keep the tension of the cable A, thereby freeing the NBU. After the NBU has cleared the ship, the load is shifted to backbone cable C, followed by the removal of the auxiliary rope.

Assuming the ocean depth to be 6000 m, the weight of the NBU in the air to be 1000 kg, backbone cable A to be an LW cable and the weight of branching cable B in the water to be comparable to the weight of an LW cable, the maximum load to be applied to backbone cable C would be about 70 kN. In this case, backbone cable C would have to be a high-tensile-strength cable (NOTS 98 kN).

If a high-tensile-strength cable cannot be used for backbone cable C, an installation support rope-based method (**Figure 5-6**) may be considered as an alternative.

The shape of the NBU is subject to further study, given that the branching unit for the VENUS project, which is used as a model here, cannot pass through a cable engine of the cable ship. However, securing sufficient storage space for a large number of NBUs near the stern deck would be unrealistic with current cable ships due to the need for a major modification. Inboard storage, in turn, would require close scrutiny in terms of the detailed location of the storage space. The last option, shifting an NBU to the stern without passing it through the cable engine, would also require close scrutiny.

In this regard, it is desirable to give the NBU a shape that would be suited to handling using a cable ship. That would solve the problems associated with the NBU storage location onboard the cable ship and installation period.

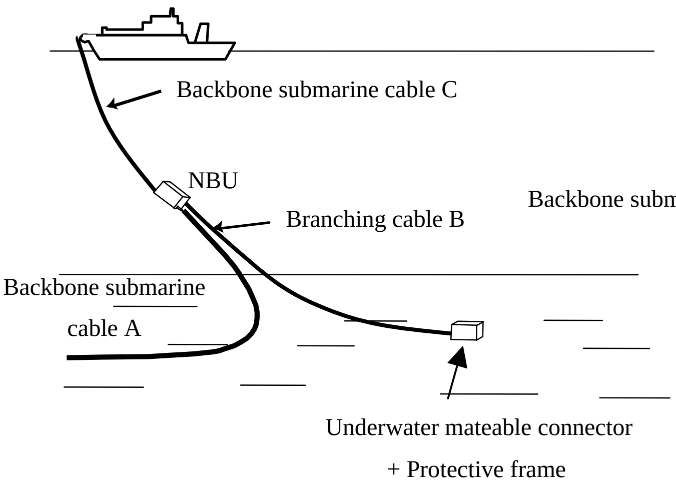

Figure 5-5 Proposed NBU Installation Method 1

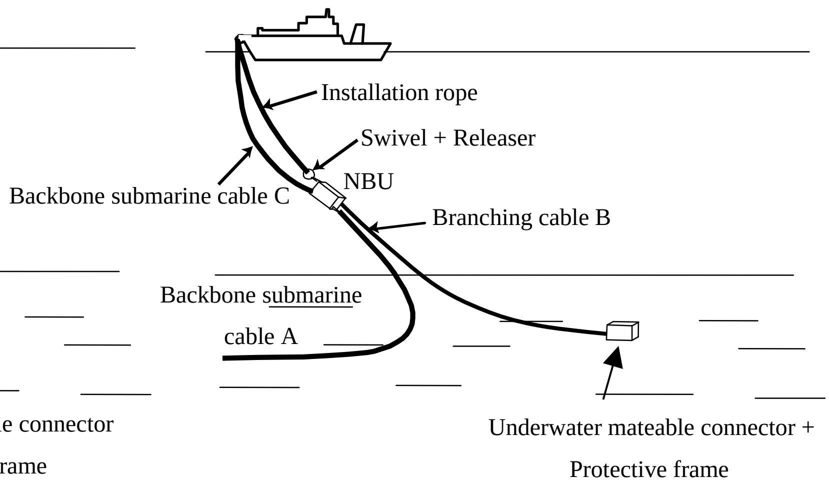

Figure 5-6 Proposed NBU Installation Method 2

5.5.2 Proposed PBU (underwater four-way) installation method

Figure 5-7 shows a proposed installation method for a power branching unit (PBU) that would accept four cables.

Under this method, the PBU is lowered off the cable ship in the same manner as the above NBU installation method. After the PBU has cleared the ship, two cables (C and D) are simultaneously paid out using two cable engines. After the PBU has reached the ocean floor, one of the cables (C) is cut off with a rope and a buoy attached at the end of the cable, or with a streaming rope at the end of cable, and the laying of the other cable (D) continues.

This installation method is a novel one which involves the installation of large equipment on the ocean floor of 6000 meters deep, simultaneous laying of two long cables using two cable engines, and has never been tried. Prior to a decision to employ it, therefore, it is necessary to carefully scrutinize it by, for example, conducting installation experiments. If an alternative configuration of the PBU based on two three-way branching units similar to conventional branching units of the underwater telecommunication cable is adopted, a method similar to the NBU installation method can be used. It is therefore necessary to further investigate the configuration of the PBU.

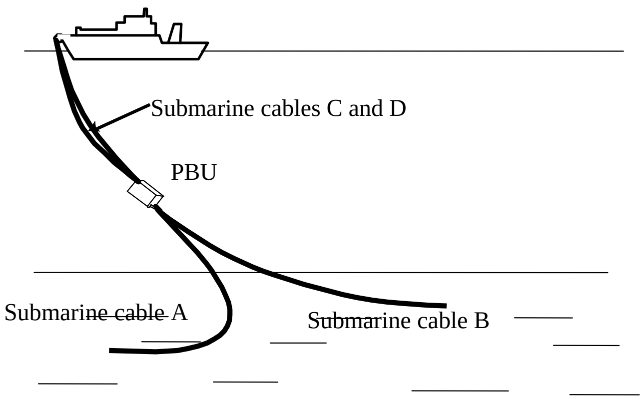

Figure 5-7 Proposed PBU Installation Method

5.6 Repair methods

In this section, new repair methods for the NBU and PBU, for which existing repair techniques - like existing construction techniques - are inadequate.

5.6.1 Proposed NBU (underwater three-way) repair method

Proposal 1

Prior to retrieving an NBU, the underwater mateable connector joining branching cable B and the UHU is demated using an ROV. Cable C is cut and hold using a cable grapnel, then the NBU-side end of the cable retrieved onto the ship. To prevent the NBU from being subjected to an excessive load when it passes through the sheave of the repair ship, it is necessary to attach auxiliary ropes to cable A and branching cable B to shift the load to them. The connection between cable A and the auxiliary rope needs to be made in water in advance.

If the auxiliary ropes used during installation can be reused, there is no need to attach new ropes. In this regard, it is necessary to evaluate the durability and other properties of auxiliary ropes in advance.

Reinstallation can be undertaken using roughly the same procedure as initial installation. When jointing a recovered cables, an insertion cable with a length that is roughly twice the depth of the water needs to be used.

Proposal 2

Prior to retrieving an NBU, the underwater mateable connector joining branching cable B and the UHU is demated using an ROV, followed by cutting of cable A near the NBU using the ROV. Cable C is then cut and hold using cable grapnel, with the NBU-side end of the cable retrieved onto the vessel. This is followed by the recovery of cable C.

The procedure of reinstallation is as follows: the end of cable A is retrieved and joined, while branching cable B is laid. The rest of the procedure is the same as the initial installation.

5.6.2 Proposed PBU (underwater four-way) repair methods

Proposal 1

For the retrieval of a PBU, a similar method to the one used to retrieve an NBU may be used.

Prior to retrieval, either of cables C and D is cut near the PBU (cable D chosen here). To do this, an ROV is necessary.

Cable C is then cut and hold, with the PBU-side end of the cable retrieved onto the vessel. This is followed by the retrieval of the cable C. Cable C needs to be a high-tensile-strength cable. To prevent the PBU from being subjected to an excessive load when it passes through the sheave of the repair ship, it is necessary to attach auxiliary ropes to cables A and B to shift the load to them. The connection between cables and auxiliary ropes needs to be made in water in advance. Cables A and B need to have a provision to facilitate the attachment of an auxiliary rope.

Reinstallation is undertaken using the same procedure as retrieval but in reverse.

Like the PBU installation method, this repair method is a novel one which has never been tried. Prior to a decision to employ it, therefore, it is necessary to carefully scrutinize it by, for example, conducting experiments. As in the case of the installation method, if an alternative configuration of the PBU based on two three-way branching units similar to conventional branching units is adopted, a method similar to either of the NBU repair methods can be used.

Proposal 2

Prior to the retrieval of the PBU, either of cables C and D and either of cables A and B are cut near the PBU (cable D and B chosen here) using an ROV.

Cable C is then cut and hold, with the PBU-side end of the cable retrieved onto the ship. This is followed by the retrieval of the entire cable C. To prevent the PBU from being subjected to an excessive load when it passes through the sheave of the repair ship, it is necessary to attach an auxiliary rope to cable A to shift the load to it. The connection between the cable and auxiliary rope needs to be made in water in advance. Cable A needs to have a provision to facilitate the attachment of an auxiliary rope.

5.7 Maintenance and management

Under the proposed scientific cable network system, the deployment of observation instruments at depths of up to 6000 meters is envisaged. To efficiently carry out the construction and maintenance of observation instruments at such great depths, a large-scale underwater operations support system that is beyond any system currently available would be necessary.

In this section, the concept of such a system will be proposed first, followed by an investigation into an underwater fault location and cause investigation system for observation instruments and other equipment.

5.7.1 Concept of underwater construction/maintenance operations support system

With the aim of streamlining construction and maintenance operations, a new multifunction deep-sea operations support system that combines the functions of a current deep-tow and ROV will be proposed. Its operating conditions and the sizes/weights of oceanographic observation systems and devices will be shown in **Tables 5-3** and **5-4**.

(1) Concept

The system should be capable of installing observation instruments, adjusting their installation locations and laying and connecting cables between UHUs and their respective observation instruments. It should be able to do so in a single operation and dive. It should also be able to lay extension cables (UHU-UHU and UHU-observation instruments) on an undulating ocean floor.

(2) Functions

- Ample payload

Work station: 2000 kg

Work vehicle: 300 kg

- Work winch: hoisting capacity 2000 kg
- High-functionality heavy-duty manipulator: 7 degrees of freedom, handling weight 150 kg
- Payload handling equipment

Water-jet cable burying machine

Sensor burying machine

- High mobility for accurate position measurement and adjustment - Work station also equipped with thrusters (active station)
- Stable movement against payload variation during cable laying, etc.

(3) Advantages

- Capable of carrying out heavy-duty operations and precision operations in one dive
- Soft-landing delivery of systems and devices onto ocean floor -> Substantial relaxation of design requirements (impact resistance) for ocean-floor equipment
(up to 30 G of impact resistance required under VENUS project)
- Capable of operating without being affected by ocean floor topography or bottom material

(4) Developmental tasks

- Handling of load change during installation/release of heavy item
- Stabilization of posture during heavy-duty operations
- Investigation into active heave compensation, etc. to add to knowledge obtained from borehole utilization system tester
- Constant-tension payout control during cable laying

Table 5-3 Working Conditions

Item			Capability
Maximum depth			6000 m
Current distribution	Depth	Surface	4 knots
		Surface - 500 m	4 knots ~ 1 knots
		500 m - 4000 m	1 knots
		4000 m - 6000 m	0.5 knots
Handling load		Installation/retrieval	2,000 kg
		Slave arms Maximum lifting load	300 kg (both arms)
Position control (Installation accuracy of observation equipment and cable)			Up to several meters
Ocean floor working environment			Able to operate under a range of topographic conditions, including undulating rocky terrain, slopes and soft ground, not to mention a flat ocean floor

Table 5-4 Sizes and Weights of Oceanographic Observation Systems and Devices

Oceanographic observation system and device	Weight in air / Weight in water	Dimensions
◆Observation station		
- Muroto system cutting-edge observation system	approx. 1800 kg / approx. 1500 kg	2.85 m L * 2.69 m W * 2.69 m H
- Kushiro-Off-Tokachi system cutting-edge observation system	approx. 1800 kg / approx. 1500 kg	3.09 m L * 2.62 m W * 2.67 m H
B-MUX	approx. 1200 kg / approx. 1000 kg	1.915 m L * 2.65 m W * 0.70 m H
J-MUX	470kg/25kg	2.20 m L * 2.05 m W * 1.33 m H
Battery pack	885kg/25kg	2.20 m L * 1.65 m W * 1.65 m H
Seismometer (in-line type)	304kg/211kg	1.7 m L/0.26m
(package type)	208kg/30kg	
Tsunami gauge (in-line type)	327kg/245kg	2.35 m L/0.26m
- Hatsushima system	approx. 880 kg / approx. 680 kg	2.89 m L * 2.4 m W * 1.93 m H
◆ Borehole-utilization observation station	approx. 3600 kg / approx. 2500 kg	2.3 m D * max 3.2 m H
◆ VENUS system		
Branching unit	820kg/630kg	2.45 m L * 1.26 m W * 1.263 m H
Hydrophone array	2100kg/km / 867kg/km	Cable 3 km long
Multi-sensor	1030kg/600kg	
Geoelectric-geomagnetic Unit	800kg/540kg	3.8 m L * 2.0 m W * 1.2 m H
Geodetic Measurements Unit	175kg/150kg	1.2 m L * 1.2 m W * 1.3 m H
Cable gripper	49.2kg/37.2kg	43.6 m L * 35 m W * 38.3 cm H
Hydraulic motor	10.6kg/8.6kg	18 cm D * max 42.8 m H
Cable Cutter	30kg/23.6kg	68 cm L * 30.5 cm W * 16 cm H
Hydraulic booster	17.5kg/14.1kg	12.8 cm D * max 73.5 cm H
◆ARENA		

Node branching unit (NBU)	approx. 1200 kg / approx. 1000 kg	
Underwater hub unit (UHU)	470kg/25kg	
Underwater observatory	Max.1800kg/1500kg	
Seismometer	Max.350kg/250kg	
Tsunami gauge	Max.350kg/250kg	Near beach
Double-armored cable	11000kg/km / 8400kg/km	
Non-armored cable	900kg/km / 500kg/km	
Hi-tension cable	1860kg/km / 730kg/km	
UMC mating and demating force (per pin)	Mating 5 lbs / Demating 2.5 lbs	Currently max. 12 pins

5.7.2 Testing equipment

Testing equipment for ARENA needs to be developed with the maintenance and management of the reliability of network components, location of faults, elucidation of their causes, investigation of the reach of their effects, and the like as its purposes. Since tests are conducted at various times/stages, including preinstallation onboard operation check, postinstallation preconnection operation check, commissioning, and fault occurrence, diverse testing equipment will be needed.

If a fault occurs in observation equipment or some other system component after installation on the ocean floor, it would be extremely inefficient and costly to investigate it by recovering such equipment onto a vessel without pinpointing the fault in advance. Table 5-5 summarizes in-situ testing methods capable of locating a fault and identifying its cause through tests conducted on underwater equipment without retrieving it onto the vessel, thus making up for the shortcomings of land-based methods.

Table 5-5 List of Underwater Tests

No.	Test item	Test target	Test method
1	Inspection of installation condition/external view	Underwater system components	TV camera-based visual inspection using ROV or AUV
2	Electrical tests	Underwater mateable connector Underwater hub unit Various sensors	Measurement of insulation resistance between pins of underwater mateable connector using underwater tester; measurement of voltage supplied to and current drawn by UHU and sensors using battery built into underwater tester
3	Optical test OTDR	Optical extension cable	OTDR test of optical signal transmission path conducted from surface by gaining access via underwater tester connected to underwater mateable connector located at end of cable
4	Electrical /optical signal measurement Analyzer, level meter, etc.	Underwater hub unit Various sensors	Checking of data communications condition and measurement of signal levels conducted from surface by gaining access via underwater tester and using ready-made data analyzer, etc.; checking of sensor operation
5	Ultrasonic tests	Ultrasound observation equipment	Measurement of sound levels, etc. of hydrophone and other underwater observation equipment using ultrasound
6	Underwater cable fault location	Underwater cable	Determination of fault location through ROV or AUV-based measurement of DC and AC currents flowing through underwater cable using magnetic sensor