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Improvement of Coastal Wave Observation Reliability by Using Composite Type Cables

Toshihiko Nagai[1], Hiromi Kado[2], Masakatsu Nakayama[3], Hiroyasu Nakashima[4], Mitsuru Inoue[5], Yasuo Simizu[6], and Tohru Nakagawa[7]

1. INTRODUCTION

Acoustic and pressure type seabed installed wave sensors have advantage in observing long period infra-gravity wave and tsunami, while buoy type wave gauges which measure acceleration of the moored buoy motion are not able to detect long period waves. That's why most of the Japanese coastal wave observation sensors are seabed installed typed ones. Nationwide Japanese coastal wave observation systems with seabed installed sensors are gradually clarifying long-period tsunami profiles and infra-gravity wave characteristics (Nagai.et.al., 1996, 1997, 2000, 2002a, 2002b).

Seabed installed wave observation systems can be divided into two groups in the data transmission method from the seabed sensor to the on-land station, one for relatively short term, simple, and cheap system without setting seabed connecting cable, the other is for permanent system with seabed cable.

The former one is named as self-recording system. Self-recorded wave data on seabed cassette is necessary to be transmitted to the surface vessels by divers. Therefore, real time wave monitoring was supposed to be difficult. If the data can be transmitted from a seabed sensor to a mooring surface buoy, real time data monitoring is possible by using wireless data communication between the buoy and the on-land station. Nevertheless such data transmission was not a practical method, because if data communication cable co-exists with a relatively stronger mooring cable, data communication cable may be damaged due to interaction with the mooring cables in high wave condition.

For the latter permanent system, Japanese Ports and Harbors Bureau of the Ministry of Land, Infrastructure and Transport (MLIT) has established Nationwide Ocean Wave information network for Ports and HArbourS (named as NOWPHAS) by cooperating with its associated agencies including Port and Airport Research Institute (PARI). In the year of 2003, NOWPHAS has 54 seabed coastal wave sensors of 20-50m deep with 2-10km off the shore. From a view point of the NOWPHAS management budget, seabed cable installation and repair takes a great part of the total cost. Almost every year at some NOWPHAS station, seabed cable suffers an accidental damage due to ship anchoring or fishery activities, for most of the NOWPHAS seabed sensors are installed off the important ports and harbors where ocean space is being utilized by various social

[1] Head, Marine Information Division, Port and Airport Research Institute, Japan
[2] ex-Director, Hakata Port and Airport Construction Office, M.L.I.T,Japan
[3] ex-Head, Port Engineering Div., Hakata Port and Airport Construction Office, M.L.I.T,Japan
[4] Section Chief, Port Engineering Div., Hakata Port and Airport Construction Office, M.L.I.T,Japan
[5] Team Manager, Kyusyu Branch, Kaijo.Co.,Japan
[6] Director, Engineering Div., Kyowashoko Co.,Japan
[7] Engineer, Kaminokawa Plant, OCC.Co.,Japan

activities. That is why expensive seabed dredging is supposed to be necessary in order to keep the cable below the seabed. Nevertheless seabed dredging cable installation is not favorable for fishermen because it may damage the fishery resources. Even if seabed cable may be installed under the seabed after expensive dredging, it may be exposed to the surface of bed due to scouring or liquefaction by high wave action.

A new type of submarine cable named as Composite Cables has been developed and put into practical use in order to solve above mentioned problems for both of mooring and seabed cables.

In this paper results of field application are introduced of the newly developed the Composite Mooring Cable and the Composite Seabed Cable (Nagai.et.al., 2003b).

2. DEVELOPMENT OF THE ON-SITE WAVE MONITORING SYSTEM WITH COMPOSITE MOORING CABLE

First Composite Cables was put into practical use for On-site Wave Monitoring System developed by Sugahara,et.al. (1999). Fig.1 explains the On-site Wave Monitoring System, consisted of seabed wave sensor, seabed battery for the sensor, Composite Mooring Cable with data transmission center part and surrounding protection part, telemeter buoy and on-land monitoring system. Either pressure type or ultrasonic acoustic type of seabed sensor is applicable. Current meter type wave directional gauge may be added to the system. On-site Wave Monitoring System realized simple coastal wave observation for limited short term with small expenditure without installing expensive seabed connection cables between the sensor and on-land monitoring station.

Table 1. Observed High Waves by On-site Monitoring System

Point	Seabed Connection	Depth (m)	Cable Length(m)	Observation (years)	H 1/3 (m)	T 1/3 (s)	H max (m)	T max (s)	Date and Time
A	UP・SP	12.5	17	7	6.30	12.3	8.95	19.0	2002/10/02 00:
B	UP・SP	12.0	18	3	5.28	12.1	6.61	12.0	1998/08/31 05:
C	UP・SP	10.0	15	1	2.20	6.5	3.60	8.8	1998/07/09 11:
D	UP	16.5	22	4	3.18	8.1	5.38	7.7	2002/04/03 23:
E	UP・SP	14.5	21	4	2.01	5.9	3.46	5.8	2001/08/21 23:
F		13.5	30	1	1.51	5.0	3.44	5.6	1999/05/27 08:
G	UP・SP	12.5	17	9 (months)	1.35	4.5	3.15	2.9	1999/10/27 10:
H	UP・SP	45.0	60	8 (months)	4.92	9.8	7.97	15.1	2001/08/21 22:
I	UP	45.0	60	8 (months)	3.42	9.5	5.51	9.6	2002/09/05 07:
(NOTE) UP:Universal Protection Pipe SP:Shock Absorber									

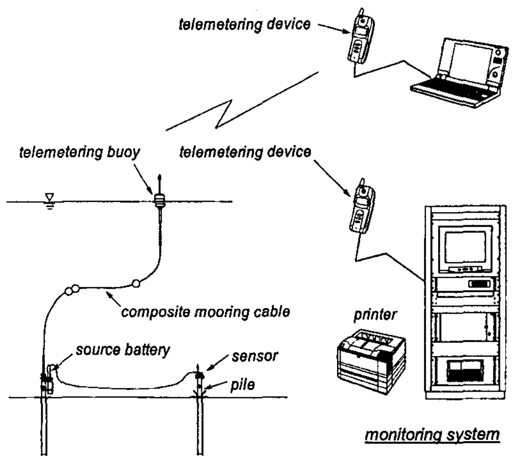

Fig.1. On-site Wave Monitoring System.

Fig.2 shows cross section of the Composite Cables for mooring connection and for seabed connection. Composite Cable united the signal transmission part and surrounding protection part consisted of many bands of steel wires, which proves the strength against the tension without loosing the flexibility. Tensile strength of the Composite Mooring Cable is *320kN*, and that of the Composite Seabed Cable is *480kN*. Fig.3 explains the seabed attachment of the cable. Special devices with universal protection pipes and coil springs were used in order to absorb shock tension and to avoid cable snapping.

The fundamental development of the on-site wave monitoring system was almost completed in 1996, and since then improving efforts have been conducted by various field application cases. Seabed attachment devices to avoid damages of cable on seabed connection part were one of the improvements. Table 1 shows results of their field application. By the end of March 2003, there exist nine field application cases in all over the Japanese coasts with water depth 10 to 45m. Observed highest significant wave height $H_{1/3}$ and period $T_{1/3}$, and corresponding maximum individual wave height H_{max} and period T_{max} in each station with their date and time is also introduced in the Table 1. At the station A, faced to the northern Pacific Ocean, the on-site system was proved to observe very high waves with maximum wave height of 8.95m without any trouble by modifying the connection of the cable and the seabed wave sensor. On-site wave monitoring system will be applied at more numbers of fields not only in Japan but also at over-sea fields, for coastal wave observation data is fundamental plan and design condition to ports and harbors development (Nagai, 2000).

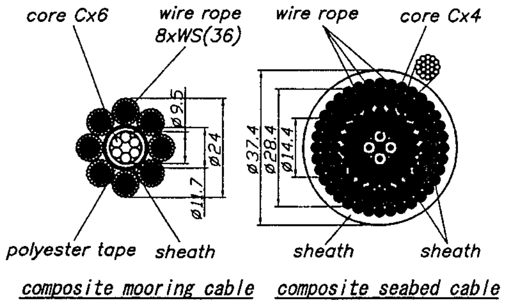

Fig.2. Cross Section of Composite Cables.

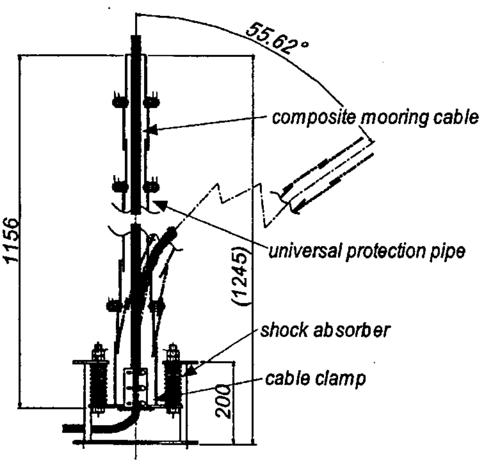

Fig.3. Seabed Attachment of the Composite Mooring cable.

3. NOWPHAS AND SEABED CABLE TROUBLES

NOWPHAS (Nationwide Ocean Wave information network for Ports and HArbourS), the Japanese coastal wave observation and analysis system, has been operated since 1970 by the Ports and Harbors Bureau of the Ministry of Land, Infrastructure and Transport (MLIT) and its associated agencies including the Port and Airport Research Institute (PARI) (Nagai.et.al., 1994; Nagai, 2002). Fig.4 shows network of the NOWPHAS in March 2003. At fifty-four stations coastal wave observation data are obtained and sent to PARI by telecommunication line. Annual NOWPHAS coastal wave information is available from the PARI's Technical Notes (Nagai.et.al., 2003a).

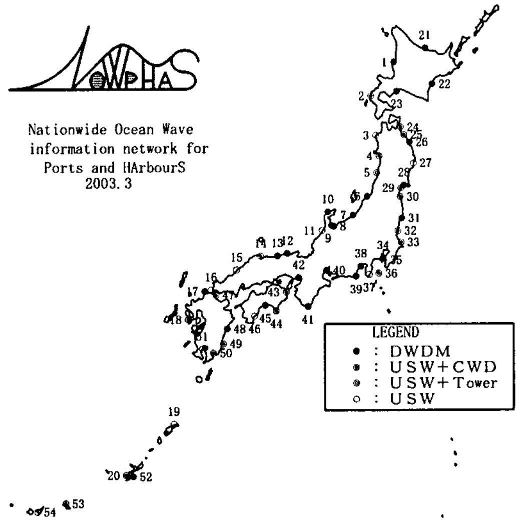

Fig.4. NOWPHAS Network (March, 2003).

Table 2 shows long-term, 100 days or longer, coastal wave data miss caused by seabed cable cut or damage during recent 10 years. Such record is to be obtained only by the Japanese NOWPHAS system, because it is usually very difficult to clarify troubles for various reasons as follows.

(1) Coastal wave observations are being conducted by various different organizations, and little communication is seen among the different organizations.

(2) Each organization is not willing to report troubles including data miss, being afraid of receiving claims.

(3) Nationwide coastal wave observation network with central controlling system is not yet established in most of the countries.

Table 2 indicates seabed cable troubles are very frequently occurs in the coastal wave observation, and one of the most important factors of precious coastal wave data miss. Therefore, all the concerned organizations and persons have been sharing the sense of necessity of improving seabed cables.

Table 2. NOWPHAS Seabed Cable Troubles

No..	Water Depth	Term of Troubles
4	29.5m	1995.11.-1996.2.
11	20.2m	1994.2.-1994.6., 2000.12.-2001.10.
12	42.0m	1997.5.-1997.10., 1999.5.-2000.1.
15	51.0m	1995.5.-1996.11.
17	41.0m	2002.5.-2002.12.
18	30.0m	1994.10.-1995.3.
20	51.0m	1997.9.-1998.3., 2001.11.-2002.5.
24	49.0m	2000.8.-2001.3.
28	49.0m	2000.1.-2000.5.
29	20.0m	1997.12-1999.1.
30	16.0m	1993.12-1994.5.
31	20.0m	1996.12.-1997.6.
32	30.0m	1993.2.-1993.12.
33	23.4m	1995.1.-1995.9., 1998.3.-1998.7.
36	49.0m	2000.7.-2001.1., 2002.9.-2003.3.
44	30.0m	1992.12.-1993.8., 1995.7.-1996.8.
49	29.0m	2000.10.-2001.2.
20	51.0m	1997.9.-1998.3., 2001.11.-2002.5.
53	25.2m	1998.12.-1999..7., 2002.7.-2003.2.

4. DESIGN AND FIELD APPLICATION OF THE SEABED COMPOSITE CABLE

The first Composite Seabed Cable was designed and applied for one of the NOWPHAS stations named Genkainada station, No.17 station in the Fig.4, by the Hakata Port and Airport Construction Office of MLIT.

4.1 Description of the Genkainada Station and DWDM Wave Sensor

The NOWPHAS Genkainada Station is the No.17 station shown in the Fig.4, where routine wave observation is being conducted using the newly developed DWDM (Doppler-type Wave Directional Meter) at water depth 41m since 1997.

Development and nationwide installation of the DWDM was recently completed as shown in the Fig.4. DWDM, a new type of wave gauge, was put into practical use in 1995 after long years' cooperation research among PARI, JAMSA (JApan Marine Surveyors Association), and Kaijo Co. DWDM enabled us to obtain directional spectrum information with one single seabed installed sensor by application of the Doppler Principle of the acoustic signal in the sea. DWDM made directional and infra-gravity wave observation possible with one single seabed installed sensor, without installing very expensive wave gauge array system (Takayama.et.al., 1994; Hashimoto. et.al., 1996).

Field application was realized at one of the NOWPHAS stations Genkainada ST. facing to the south western Japan Sea, where seabed cable renewal was conducted for 800m length between seabed DWDM sensor of 41m deep and the cable connection terminal (Joint Box) of 30m deep. The original cable was damaged and by some human oriented accident on May 6th, 2002.

Fig.5 indicates seabed cable location at the station. On-land station with data processing system locates on the Ohshima Island, and seabed DWDM sensor locates at water depth 41m about 4km off the island. The on-land station and the seabed sensor is connected with seabed cable, and the 4km length seabed cable is divided into two part with a Joint Box at the water depth 30m.

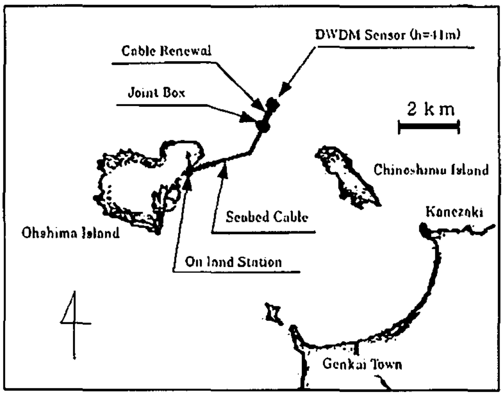

Fig.5. Seabed Cable Renewal Location.

4.2 Designing and Fabrication of the Composite Seabed Cable

After the seabed cable damage, authors immediately started to study how to recover the system and decided to apply newly designed Composite Type Seabed Cable. The specification of the Seabed Composite Cable was decided to satisfy the following conditions.

(1) Central data transmission part of the Composite Seabed Cable should be same to the existing seabed cables in order to avoid troubles of cable connection to the joint box and the seabed sensor.

(2) Composite Seabed Cable should be stronger against tension than existing types of seabed cables.
(3) Composite Seabed Cable should be more flexible than existing types of seabed cables, to increase installation workability and to follow seabed topography well.
(4) At the installation, dredging should be voided in order to keep good fishery resources on the seabed. Therefore, Composite Seabed Cable should have higher density more than 3.0 in order to promote self-depression into the liquefied seabed sand, avoiding the cable exposure.

Table 3 shows comparison of specification of the Composite Seabed Cable with existing non-armored, single armored and double armored types of cable. Cable diameter 37.4mm of the Composite Seabed Cable is a little smaller than the double-armored typed one. Nevertheless, tensile strength of the Composite Seabed Cable 420kN is more than four times of the double-armored typed one, and more than ten times of the single-armored typed one. In addition stiffness 5.6Nm^2 is much smaller than double and single armored existing types.

Stiffness B of the cable is defined in the equation (1).

$$B = (L^3/3)(F/y) \qquad (1)$$

where, L : Length of a single beam with one side fixed and the other side free

F : Vertical out-force to the beam at the free side

y :Vertical displacement of the beam the free side

Therefore, smaller value of stiffness B means that the cable is more flexible.

(1) Electric Resistance Test (2) Diameter Test

Photo.1. Laboratory Test of the Composite Cable.

Photo.1 shows laboratory tests of the Seabed Composite Cable in the factory.

4.3 Cable Installation Work

Field installation of the Composite Seabed Cable was conducted on December 14th, 2002, after fabricating the cable in the plant. In spite of severe winter sea-state in the area, as the cable had fairy good flexibility, field installation of the 800m long seabed cable was completed within 5 hours by using special working vessels.

Table 3. Specification of Each Type of Seabed Cable

Cable type	Cable diameter [mm]	Weight (in the air) [kg/m]	Tensile strength [kN]	Specific gravity [−]	Stiffness [N・m^2]
Non-armored type	14.4±1.0	0.28	2.3	1.7	0.12
Single-armored type	26.8±3.0	1.73	43.0	3.0	13.8
Double-armored type	39.2±4.0	4.20	110.0	3.4	37.4
New Composite type	37.4±3.7	3.42	480.0	3.1	5.6

Photo.2 shows the board of the cable layer barge and the cable dram. The dram diameter is generally determined as 16 times of the cable diameter in normal armored cable installation. In case of the Composite Seabed Cable, smaller diameter dram may be applicable because of its good flexibility. Nevertheless, authors applied a dram for double-armored type of cable this time, for the most suitable dram diameter for the new cable was not determined yet.

(1) Installation Barge (2) On the Barge Board

(3) Cable Dram (4) Edge of the Barge

Photo.2. Field Installation of the Composite Cable.

Fig.6 indicates the installation work. Authors took special care in fixing both edge of the cable in order to avoid the tension out-force acting the non-armored weak part of both edges. Fig.7 shows the attachment of the both edges of the cable. By using 3 cable cramps in both sides, tension transmits to the support foundation piers directly without transmitting to the non-armored part of the cable.

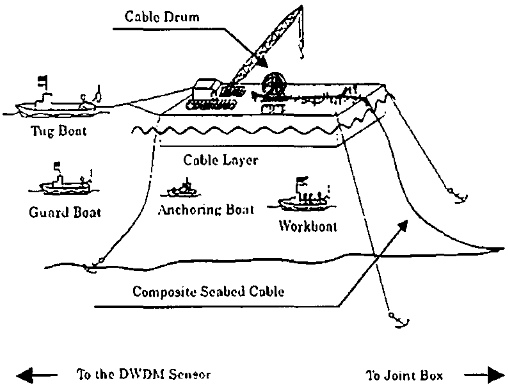

Fig.6. Field Installation Work Explanation.

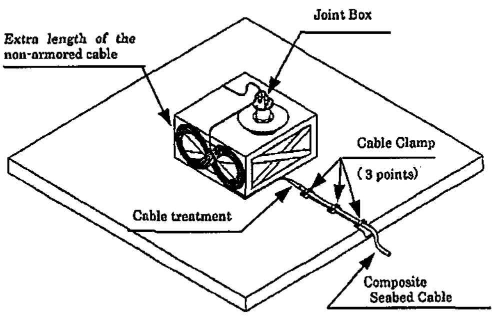

Fig.7. Attachment of the Composite Cable to the Support.

4.4 Wave Observation after Repair Seabed Cable

Fig.8 shows observed wave history after the cable renewal including the highest significant wave ($H_{1/3}$ = 5.05m) record at 4:00 on January 29th, 2003, and the highest individual wave (H_{max} = 7.46m) record at 10:00 on February 20th, 2003. There has been no wave data miss after the renewal including in very severe sea states, that means the Composite Seabed Cable has been well functioning up to the present time.

Photo.4 shows the seabed cable state taken on March 26th, about 100 days after installation of the cable. Lower half part of the cable cross section was in the seabed sand, and upper half was upon the seabed. The cable kept its original route without suffering horizontal displacement. This means that the seabed cable is gradually and slowly sinking into the seabed sand by its own weight keeping its original horizontal location as planned at the first design stage.

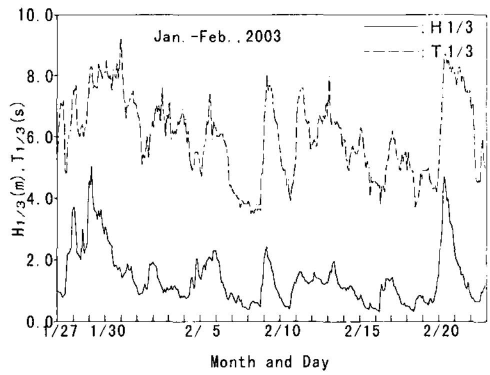

Fig.8. Observed Significant Waves after Cable Renewal.

(1) In-Sea-Water Welding (2) Edge Attachment

Photo.3. Composite Cable Edge Attachment to the Support.

Photo.4. Seabed Cable 100 Days after Renewal (2003.3.26.).

5. CONCLUDING REMARKS

Nowadays coastal wave observation data have been increasing their importance by being utilized for sea state prediction of maritime construction works with real-time analysis combined with worldwide meteorological information. Nevertheless, reliability of coastal wave observation information is dependent to the reliability of the submarine cable, for one of the important causes of data miss is submarine cable trouble, either damaged or cut. Composite type submarine cable both for mooring type and seabed type will reduce such cable troubles and increase reliability of coastal wave observation.

In this paper authors introduced newly developed Composite Mooring Cable and Composite Seabed Cable, both being unified signal transmission center part and surrounding protection part consisted of many bands of steel wires, which proves the strength against the tension out-force without loosing the flexibility.

Authors are willing to continue to work to improve the Composite types of submarine cables for more reliable coastal wave observation.

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