

Mooring systems for time-series observation for biogeochemistry in the northwestern North Pacific: design, preparation and mooring work

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Abstract For the better understanding of carbon cycle in the northwestern North Pacific where rough sea condition frequently refuses oceanographic observation by research vessel, time-series observation for the biogeochemistry with mooring system has been requested strongly. Mutsu Institute for Oceanography (MIO) challenged to deploy the mooring system that is anchored on the sea floor at > 5,000 m depth and its top with automatic instruments is located in the euphotic layer, upper 30 – 50 m. In order to enable this deployment, behaviors of mooring system such as tilt and depth for instruments during deployment and observation were simulated, and precise lengths of wire and nylon ropes used for mooring systems were measured under the mooring tension on land. Based on these procedures, two types mooring systems were deployed at stations K-1 (51°N, 165°E) and K-3 (39°N, 160°E) in October 2002 and recovered in November 2003. Mooring systems were successfully deployed within 300 m from a “target” points and depths of top of mooring systems could be located between 40 – 60 m for K-1 mooring and 50 – 70 m for K-3 mooring as we designed except high current period.

Keywords: pre-stretch, BGC mooring, PO Mooring, time-series, northwestern North Pacific

1. Introduction

The Northwestern North Pacific is the terminal zone of the deep-sea water circulation, resulting the high productivity. As diatom species without carbonate test are pre-dominant, the biological activity in this area plays an important role in absorbing atmospheric CO₂.

In September 2000, Mutsu Institute for Oceanography (MIO) initiated a project named “HIgh LATitude Time-Series observational study (HILATS)” with using two types mooring systems: One is for biogeochemistry and consists of automatic sampler collecting such as seawater, zoo and phytoplankton and sinking particles (BGC mooring systems: Fig. 1 (a)). The other is for physical oceanography and consists of CTD / ACM profiler (PO mooring systems: Fig. 1 (b)). This project has been conducted with cooperation of Woods Hole Oceanographic Institution (WHOI).

This report introduces the above mooring system focusing on its concept, design, preparation and mooring works.

2. Design of mooring system

2.1 Principal points

The most important point of these mooring systems is how precisely automatic samplers just below a top buoy of mooring systems are located within the euphotic layer (upper 50 m). On the other hand, these instruments should be never installed upper 30 m because of rough

seas with waves exceeding 20 m in height and presence of ships with drafts >10 m. Therefore the following points on materials and design were considered.

- (1) A top buoy of mooring system should be located around 30 m below sea surface precisely. In order to keep mooring system straight against the external force (wave and current), a 64” syntactic form buoy was selected. ” is the inch of length unit. Its buoyancy was adjusted to be approximately 1.3 ton and two times larger than that used for Acoustic Doppler Current Profiler (ADCP) mooring system (Ito et al., 1995)¹⁾ in the project “Tropical Ocean Climate Study (TOCS)” (<http://www.jamstec.go.jp/tocs/E/>).
- (2) In order to avoid significant elongation by high tension and partition by “fish bite”, 1/4” or 5/16” torque-balanced wire rope with polyethylene jacket (Wire Rope Corporation of America, Inc.) were selected as a main mooring rope. Unlike an ordinary wire rope, this wire rope has a fewer torsion resulting a smaller elongation and a fewer occurrence of kink. We use wire ropes of 5/16” for “BGC” mooring systems of upper 1,000 m and 1/4” for below 1,000 m in order to reduce weight and hydrodynamic resistance, while 1/4” wire ropes was used mainly for “PO” mooring systems with MMP.
- (3) In order to recover mooring system certainly, tandem-releaser system (Edgetech:Model 8242XS) was selected.

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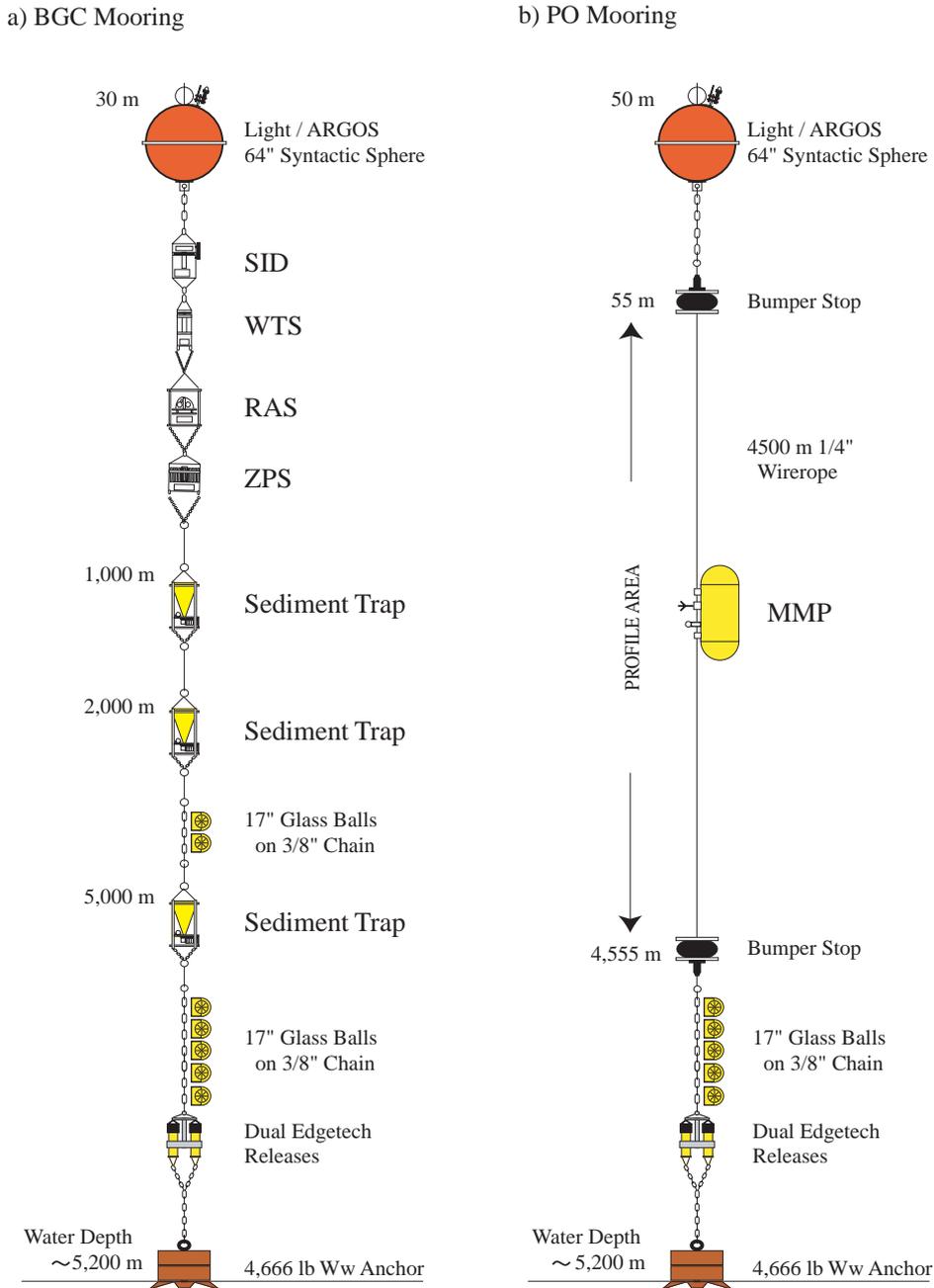


Figure 1: Schematic diagram of Mooring System for Time-Series Observational Study

- (4) An impact load occurs when anchor is dropped into the sea surface and lands on the sea floor. As a shock absorber, flotation systems of glass balls were installed just above a releaser system and nylon rope of 1" was inserted between an anchor and a releaser system. This flotation system has enough buoyancy to hold whole mooring system even if top buoy of 64" syntactic foam buoy is lost.
- (5) Imawaki reported that the weight of anchor should be heavier than high tension of 1.25 times and more (1976)². In order to keep mooring system straight

- with high tension (1.3 ton) and increase friction resistance, heavy anchor of approximately 2 ton with a "mace plate", which was like a spike to grip seafloor, is prepared.
- (6) A positioning system (Seimac ARGOS compact mooring locator: CML) is installed on respective top buoys. When a top buoy appears on the sea surface intentionally or accidentally, ARGOS CML starts to transmit signal of its position to land. Therefore it enables us to know its position easily.

Table 1: BGC Mooring Design Tention

	K-1 BGC Mooring Description	Joint	Item Length (m)	Total (kg)	Mooring Length (m)	Mooring Weight (kg)	Above Bottom (m)	Mooring Depth (m)	Safety Rate
1	64" Syntatic Sphere		2.270	-1360.8		-1360.8	5106.6	29.8	
	Hardware	L	0.280	3.6	2.6	-1357.1	5104.3	32.1	
2	3/4" Proof Coil Chain		5.000	40.0	7.6	-1317.1	5104.0	32.4	3.64
	Hardware	F	0.255	2.4	7.8	-1314.7	5099.0	37.4	
3	Instrument - "SID" - (OOS)		1.694	59.0	9.5	-1255.7	5098.8	37.6	4.44
	Hardware	H	0.235	1.9	9.7	-1253.8	5097.1	39.3	
4	Instrument - "WTS"		2.855	56.7	12.6	-1197.1	5096.9	39.5	4.57
	Hardware	H	0.235	1.9	12.8	-1195.2	5094.0	42.4	
5	Instrument - "RAS"		2.285	35.0	15.1	-1160.2	5093.8	42.6	4.79
	Hardware	H	0.235	1.9	15.3	-1158.2	5091.5	44.9	
6	Instrument - "ZPS"		3.355	26.0	18.7	-1132.2	5091.2	45.2	4.90
	Hardware	H	0.235	1.9	18.9	-1130.3	5087.9	48.5	
7	3-TON Miller Swivel		0.161	3.2	19.1	-1127.1	5087.7	48.7	2.66
	Hardware	H	0.235	1.9	19.3	-1125.2	5087.5	48.9	
8	500M 5/16" Wire - (Z)		499.329	106.5	518.7	-1018.8	5087.3	49.1	3.44
	Hardware	H	0.235	1.9	518.9	-1016.8	4587.9	548.5	
9	403 Meters 5/16" Wire - (AA)		402.258	85.8	921.2	-931.1	4587.7	548.7	3.76
	Hardware	H	0.235	2.2	921.4	-928.9	4185.4	951.0	
10	50 Meters 5/16" Wire - (AO)		49.919	10.6	971.3	-918.2	4185.2	951.2	3.81
	Hardware	I	0.215	2.2	971.5	-916.1	4135.3	1001.1	
11, 12, 13	Sediment Trap	O	3.571	35.0	975.1	-881.1	4135.1	1001.3	6.32
	Hardware	J	0.046	0.4	975.1	-880.6	4131.5	1004.9	
14	5 Meters 3/8" Trawler Chain		5.000	10.1	980.1	-870.5	4131.5	1004.9	3.45
	Hardware	A	0.210	1.3	980.3	-869.2	4126.5	1009.9	
15	500 Meters 1/4" Wire - (O)		499.585	70.2	1479.9	-798.9	4126.2	1010.2	2.88
	Hardware	A	0.210	1.3	1480.1	-797.6	3626.7	1509.7	
16	440.1 Meters 1/4" Wire - (R)		439.560	61.8	1919.7	-735.8	3626.4	1510.0	3.13
	Hardware	A	0.210	1.3	1919.9	-734.4	3186.9	1949.5	
17	50 Meters 1/4" Wire - (AL)		50.103	7.0	1970.0	-727.4	3186.7	1949.7	3.16
	Hardware	K	0.200	1.4	1970.2	-726.0	3136.6	1999.8	
18, 19, 20	Sediment Trap	O	3.571	35.0	1973.8	-691.0	3136.4	2000.0	6.04
	Hardware	J	0.046	0.4	1973.8	-690.6	3132.8	2003.6	
21	2 Meters 3/8" Trawler Chain		2.700	5.5	1976.5	-685.1	3132.8	2003.6	4.38
	Hardware	A	0.210	1.3	1976.7	-683.8	3130.1	2006.3	
22	500 Meters 1/4" Wire - (#A)		501.054	70.5	2477.8	-613.3	3129.8	2006.6	3.75
	Hardware	A	0.210	1.3	2478.0	-612.0	2628.8	2507.6	
23	500 Meters 1/4" Wire - (#B)		500.932	70.4	2978.9	-541.5	2628.6	2507.8	4.25
	Hardware	A	0.210	1.3	2979.1	-540.2	2127.7	3008.7	
24	20 Meters 1/4" Wire - (#5/20)		20.153	2.8	2999.3	-537.4	2127.4	3009.0	4.28
	Hardware	A	0.210	1.3	2999.5	-536.1	2107.3	3029.1	
25	20 Meters 1/4" Wire - (#6/20)		20.153	2.8	3019.7	-533.2	2107.1	3029.3	4.31
	Hardware	A	0.210	1.3	3019.9	-531.9	2086.9	3049.5	
26	4-17" Glassballs on 3/8" Trawler		4.000	-99.6	3023.9	-631.5	2086.7	3049.7	4.75
	Hardware	A	0.210	1.3	3024.1	-630.2	2082.7	3053.7	
27	4-17" Glassballs on 3/8" Trawler		4.000	-99.6	3028.1	-729.8	2082.5	3053.9	4.11
	Hardware	A	0.210	1.3	3028.3	-728.5	2078.5	3057.9	
28	500 Meters 1/4" Wire - (#C)		501.065	70.5	3529.4	-658.1	2078.3	3058.1	3.50
	Hardware	A	0.210	1.3	3529.6	-656.7	1577.2	3559.2	
29	500 Meters 1/4" Wire - (#D)		500.708	70.4	4030.3	-586.3	1577.0	3559.4	3.92
	Hardware	A	0.210	1.3	4030.5	-585.0	1076.3	4060.1	
30	500 Meters 1/4" Wire - (#E)		501.020	70.5	4531.5	-514.5	1076.1	4060.3	4.47
	Hardware	A	0.210	1.3	4531.7	-513.2	575.1	4561.3	
31	4-17" Glassballs on 3/8" Trawler		4.000	-99.6	4535.7	-612.9	574.9	4561.5	4.90
	Hardware	A	0.210	1.3	4535.9	-611.5	570.9	4565.5	
32	200 Meters 1/4" Wire - (FF)		199.878	28.1	4735.8	-583.4	570.7	4565.7	3.94
	Hardware	A	0.210	1.3	4736.0	-582.1	370.8	4765.6	
33	50 Meters 1/4" Wire - (#FF)		50.232	7.1	4786.2	-575.0	370.6	4765.8	4.00
	Hardware	K	0.195	2.2	4786.4	-572.8	320.3	4816.1	
34, 35, 36	Sediment Trap	O	3.571	35.0	4790.0	-537.8	320.1	4816.3	11.62
	Hardware	J	0.046	0.4	4790.1	-537.4	316.6	4819.8	
37	3 Meters 3/8" Trawler Chain		2.000	4.1	4792.1	-533.4	316.5	4819.9	5.62
	Hardware	A	0.210	1.3	4792.3	-532.0	314.5	4821.9	
38	100 Meters 1/4" Wire - (UU)		100.009	14.1	4892.3	-518.0	314.3	4822.1	4.44
	Hardware	A	0.210	1.3	4892.5	-516.6	214.3	4922.1	

Table 1: (continued).

	K-1 BGC Mooring Description	Joint	Item Length (m)	Total (kg)	Mooring Length (m)	Mooring Weight (kg)	Above Bottom (m)	Mooring Depth (m)	Safety Rate
39	50 Meters 1/4" Wire - (YY)		49.993	7.0	4942.5	-509.6	214.1	4922.3	4.51
	Hardware	A	0.210	1.3	4942.7	-508.3	164.1	4972.3	
40	25 Meters 1/4" Wire - (#2/25)		25.108	3.5	4967.8	-504.7	163.9	4972.5	4.56
	Hardware	A	0.210	1.3	4968.0	-503.4	138.8	4997.6	
42	25 Meters 1/4" Wire- (#3/25)		25.147	3.5	4993.2	-499.9	138.6	4997.8	4.60
	Hardware	A	0.210	1.3	4993.4	-498.6	113.4	5023.0	
	20 Meters Adj 1/4" Wirerope		20.000	2.8	5013.4	-495.7	113.2	5023.2	4.64
	Hardware	A	0.210	1.3	5013.6	-494.4	93.2	5043.2	
43	5M 1/4" Jac. Wirerope		5.109	0.7	5018.7	-493.7	93.0	5043.4	4.66
	Hardware	A	0.210	1.3	5018.9	-492.4	87.9	5048.5	
44	5 Meters 3/8" Trawler Chain		5.000	10.1	5023.9	-482.2	87.7	5048.7	6.22
	Hardware	A	0.210	1.3	5024.1	-480.9	82.7	5053.7	
45	4-17" Glassballs on 3/8" Trawler		4.000	-99.6	5028.1	-580.5	82.5	5053.9	5.17
	Hardware	A	0.210	1.3	5028.3	-579.2	78.5	5057.9	
46	4-17" Glassballs on 3/8" Trawler		4.000	-99.6	5032.3	-678.8	78.3	5058.1	4.42
	Hardware	A	0.210	1.3	5032.5	-677.5	74.3	5062.1	
47	4-17" Glassballs on 3/8" Trawler		4.000	-99.6	5036.5	-777.2	74.1	5062.3	3.86
	Hardware	A	0.210	1.3	5036.7	-775.8	70.1	5066.3	
48	4-17" Glassballs on 3/8" Trawler		4.000	-99.6	5040.7	-875.5	69.9	5066.5	3.43
	Hardware	A	0.210	1.3	5040.9	-874.1	65.9	5070.5	
49	4-17" Glassballs on 3/8" Trawler		4.000	-99.6	5044.9	-973.8	65.6	5070.8	3.08
	Hardware	A	0.210	0.4	5045.2	-973.4	61.6	5074.8	
50	4-17" Glassballs on 3/8" Trawler		4.000	-99.6	5049.2	-1073.0	61.4	5075.0	2.80
	Hardware	A	0.210	0.4	5049.4	-1072.6	57.4	5079.0	
51	4-17" Glassballs on 3/8" Trawler		4.000	-99.6	5053.4	-1172.2	57.2	5079.2	2.56
	Hardware	A	0.210	0.4	5053.6	-1171.8	53.2	5083.2	
52	4-17" Glassballs on 3/8" Trawler		4.000	-99.6	5057.6	-1271.5	53.0	5083.4	2.36
	Hardware	A	0.210	0.4	5057.8	-1271.0	49.0	5087.4	
53	4-17" Glassballs on 3/8" Trawler		4.000	-99.6	5061.8	-1370.7	48.8	5087.6	2.19
	Hardware	A	0.210	0.4	5062.0	-1370.3	44.8	5091.6	
54	5 Meters 3/8" Trawler Chain		5.000	10.1	5067.0	-1360.1	44.6	5091.8	2.21
	Hardware	C	0.235	2.1	5067.2	-1358.0	39.6	5096.8	
55,56	Dual EGG Acoustic Releases	M	1.945	66.0	5069.2	-1292.0	39.4	5097.0	4.94
	Hardware	D	0.245	2.7	5069.4	-1289.3	37.4	5099.0	
57	5 Meters 3/8" Trawler Chain		5.000	10.1	5074.4	-1279.1	37.2	5099.2	2.35
	Hardware	C	0.235	2.1	5074.7	-1277.0	32.2	5104.2	
58	20 Meters 1" Nylon		21.794	0.3	5096.5	-1276.7	31.9	5104.5	3.96
	Hardware	C	0.235	2.1	5096.7	-1274.6	10.1	5126.3	
59	5 Meters 3/8" Trawler Chain		5.000	10.1	5101.7	-1264.4	9.9	5126.5	2.37
	Hardware	D	0.245	2.7	5101.9	-1261.7	4.9	5131.5	
	4000 Lb Ww Anchor		0.662	2268.0	5102.6	1006.2	4.7	5131.7	
	OVERALL MOORING LENGTH		5102.592		Depth		4.0	5132.4	

2.2 Tension and strength of mooring system

(1) Designed tension and safety rate

Tables 1 and 2 show designed tension (load) and safety rate (the ratio of designed tension to official working load limit) on respective parts for BGC mooring and PO mooring, respectively. It can be seen that the largest tension is loaded on a releaser and 3/8" chain with glass balls just above a releaser (1.4tf). However, safety rate of even these parts are higher than two (2.19 for BGC Mooring system and 2.16 for PO mooring system).

(2) Tilt and variation of tension of mooring system under static load

In order to design mooring systems, tilt and variation of tension of mooring system under static load was computed with software "MOORDSGN" developed by

Dr. Clark Darnall, senior engineer of Polar Science Center, Applied Physics Laboratory, University of Washington. With data of cross section area of mooring system (mooring ropes and instruments) and data of current velocity at any 6 layers, tilt, variation of tension and depths for principal parts respective instruments can be calculated. After input the length and material from Tables 1 and 2, cross section area, drag coefficient and so on are given automatically.

Assuming that various current velocities from 0 cm sec⁻¹ to 50 cm sec⁻¹ at 0 m decrease with increasing depth monotonically to 1000 m, where velocity is 0 cm sec⁻¹, tilt of mooring systems were simulated (Fig. 2, a for BGC mooring system and Fig. 2, b for PO mooring systems). Tables 3 and 4 summarize horizontal distances

Table 2: PO Mooring Design Tention

	K-1 PO Mooring Description	Joint	Item Length (m)	Item Weight (kg)	Mooring Length (m)	Mooring Weight (kg)	Above Bottom (m)	Below Surface (m)	Safety Rate
1	64" Syntatic Sphere		2.27	-1360.8	2.3	-1360.8	5068.0	50.0	
	Hardware	L	0.28	3.6	2.6	-1357.2	5065.8	52.2	
2	5 Meters 3/4" Proof Coil Chain		5.00	40.0	7.6	-1317.2	5065.5	52.5	3.64
	Hardware	F	0.26	2.4	7.8	-1314.7	5060.5	57.5	
3	3-TON Miller Swivel		0.16	3.2	8.0	-1311.5	5060.2	57.8	2.29
	Hardware	B	0.23	1.6	8.2	-1309.9	5060.1	57.9	
4	4500 Meters 1/4" Wire (C)		4500.15	632.8	4508.3	-677.2	5059.8	58.1	3.40
	Hardware	B	0.23	1.6	4508.6	-675.6	559.7	4558.3	
5	3-TON Miller Swivel		0.16	3.2	4508.7	-672.4	559.5	4558.5	4.46
	Hardware	B	0.23	1.6	4509.0	-670.8	559.3	4558.7	
6	20 Meters 1/4" Wire - (#1/20)		20.13	2.8	4529.1	-667.9	559.1	4558.9	3.44
	Hardware	A	0.21	1.3	4529.3	-666.6	539.0	4579.0	
7	4-17" Glassballs on 3/8" Trawler		4.00	-99.6	4533.3	-766.3	538.7	4579.2	3.92
	Hardware	A	0.21	1.3	4533.5	-765.0	534.7	4583.2	
8	2-17" Glassballs on 3/8" Trawler		2.00	-24.9	4535.5	-789.9	534.5	4583.5	3.80
	Hardware	A	0.21	1.3	4535.7	-788.6	532.5	4585.5	
9	430 Meters 1/4" Wire - (#0)		430.66	60.6	4966.4	-728.0	532.3	4585.7	3.16
	Hardware	A	0.21	1.3	4966.6	-726.7	101.7	5016.3	
10	25 Meters 1/4" Wire - (#1/25)		25.11	3.5	4991.7	-723.2	101.5	5016.5	3.18
	Hardware	A	0.21	1.3	4991.9	-721.9	76.3	5041.7	
11	15 Meters 1/4" Wire - (#1/25)		15.00	2.1	5006.9	-719.8	85.4	5041.9	3.20
	Hardware	A	0.21	1.3	5007.1	-718.5	70.4	5056.9	
12	5.7 Meters 3/8" Trawler Chain		5.70	11.6	4997.6	-710.3	76.1	5057.1	4.22
	Hardware	A	0.21	1.3	4997.8	-709.0	70.4	5062.8	
13	4-17" Glassballs on 3/8" Trawler		4.00	-99.6	5001.8	-808.7	70.2	5063.0	3.71
	Hardware	A	0.21	1.3	5002.0	-807.4	66.2	5067.0	
14	4-17" Glassballs on 3/8" Trawler		4.00	-99.6	5006.0	-907.0	66.0	5067.2	3.31
	Hardware	A	0.21	1.3	5006.2	-905.7	62.0	5071.2	
15	4-17" Glassballs on 3/8" Trawler		4.00	-99.6	5010.2	-1005.4	61.8	5071.4	2.98
	Hardware	A	0.21	1.3	5010.4	-1004.1	57.8	5075.4	
16	4-17" Glassballs on 3/8" Trawler		4.00	-99.6	5014.4	-1103.7	57.6	5075.6	2.72
	Hardware	A	0.21	1.3	5014.7	-1102.4	53.6	5079.6	
17	4-17" Glassballs on 3/8" Trawler		4.00	-99.6	5018.7	-1202.1	53.4	5079.8	2.50
	Hardware	A	0.21	1.3	5018.9	-1200.8	49.4	5083.8	
18	4-17" Glassballs on 3/8" Trawler		4.00	-99.6	5022.9	-1300.4	49.2	5084.0	2.31
	Hardware	A	0.21	1.3	5023.1	-1299.1	45.2	5088.0	
19	4-17" Glassballs on 3/8" Trawler		4.00	-99.6	5027.1	-1398.8	45.0	5088.2	2.14
	Hardware	A	0.21	1.3	5027.3	-1397.5	41.0	5092.2	
20	5 Meters 3/8" Trawler Chain		5.00	10.1	5032.3	-1387.3	40.8	5092.5	2.16
	Hardware	C	0.24	2.1	5032.5	-1385.2	35.8	5097.5	
21	Dual EGG Acoustic Releases		1.95	66.0	5034.5	-1319.2	35.5	5097.7	4.40
	Hardware	D	0.25	2.7	5034.7	-1316.5	33.6	5099.6	
22	5 Meters 3/8" Trawler Chain		5.00	10.1	5039.7	-1306.3	33.3	5099.9	2.30
	Hardware	C	0.24	2.1	5039.9	-1304.2	28.3	5104.9	
23	20 Meters 1" Nylon (#2)		21.95	0.3	5061.9	-1303.9	28.1	5105.1	3.83
	Hardware	C	0.24	2.1	5062.1	-1301.8	6.1	5127.1	
24	5 Meters 3/8" Trawler Chain		5.00	10.1	5067.1	-1291.7	5.9	5127.3	2.32
	Hardware	D	0.25	2.7	5067.4	-1289.0	0.9	5132.3	
25	4000 Lb Ww Anchor		0.66	2268.0	5068.0	979.0	0.7	5132.5	
	OVERALL MOORING LENGTH		5083.24				0.0	5133.2	

of instruments from a anchored point and depths of time-series instruments and principal parts under static load.

Based on previous observation data, current velocity near sea surface in the northwestern North Pacific is expected to be at most 30 cm sec⁻¹. In this case, subsurface instruments except sediment traps are located between 60 and 70 m, which is still within the euphotic zone of this area. Therefore our mooring design is appropriate for this area. On the other hand, a top of PO mooring

system was expected to be deepened to approximately 170 m under high current velocity of 30 cm sec⁻¹.

It is noted that the inclination of PO mooring is larger than that of BGC mooring although horizontal cross sectional area of PO mooring is smaller than that of BGC mooring. It might be attributed to a problem in segment numbers for PO mooring. If we simulate the inclination of PO mooring line with segment numbers of 9 (500 m × 9) instead of 1 (4,500 m × 1), the inclination

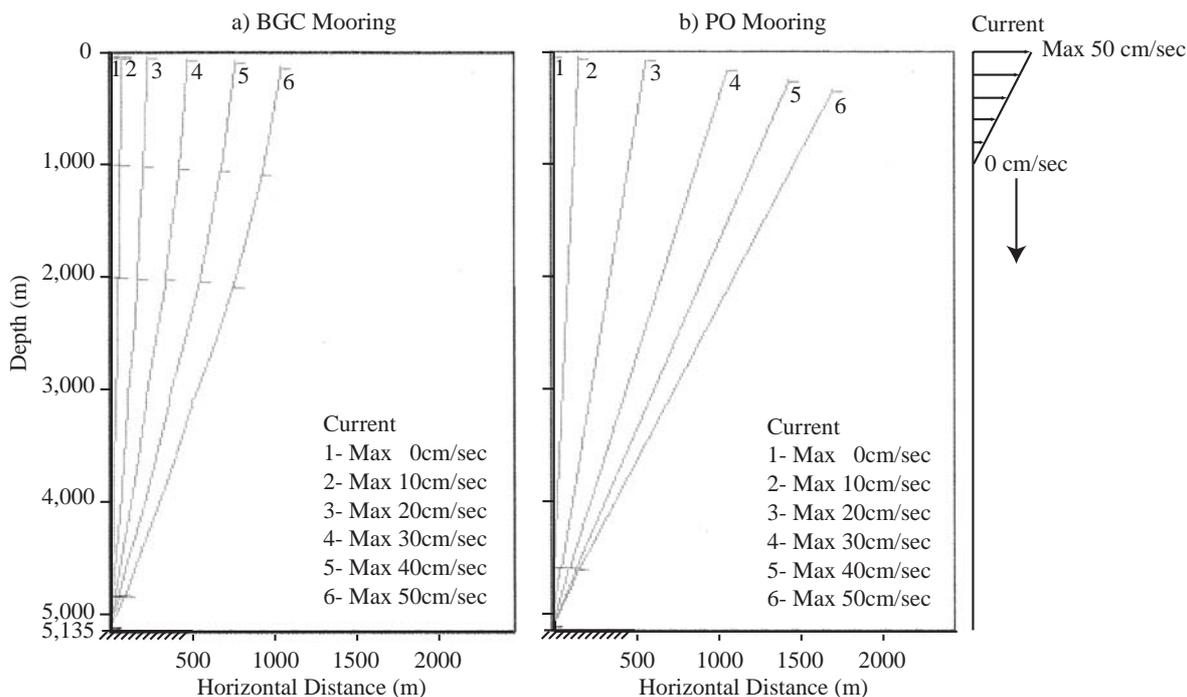


Figure 2: Result of Static Calculation

Table 3: Result of Static Calculation for BGC Mooring

Current	Top Buoy	Horizontal Distance	SID	WTS	RAS	ZPS	Sediment Trap 1,000m	Sediment Trap 2,000m	Sediment Trap 4,818m	Releaser
1. 0cm/sec	30m	0m	37.9m	39.8m	42.9m	45.4m	1,001m	2,001m	4,819m	5,100m
2. 10cm/sec	31m	72m	38.5m	40.4m	43.5m	46.0m	1,002m	2,002m	4,819m	5,100m
3. 20cm/sec	35m	223m	43.2m	45.1m	48.2m	50.7m	1,006m	2,005m	4,820m	5,100m
4. 30cm/sec	53m	469m	61.0m	62.9m	66.0m	68.5m	1,023m	2,020m	4,821m	5,100m
5. 40cm/sec	90m	754m	97.9m	99.8m	102.9m	105.4m	1,057m	2,050m	4,825m	5,100m
6. 50cm/sec	142m	1,023m	149.5m	151.4m	154.5m	157.0m	1,106m	2,092m	4,830m	5,101m

Table 4: Result of Static Calculation for PO Mooring

Current	Top Buoy	Horizontal Distance	4,500m Wire Top	4,500m Wire Bottom	Releaser
1. 0cm/sec	50m	0m	58.1m	4,575m	5,097m
2. 10cm/sec	53m	160m	60.6m	4,576m	5,097m
3. 20cm/sec	83m	574m	90.8m	4,578m	5,097m
4. 30cm/sec	161m	1,055m	169.5m	4,585m	5,097m
5. 40cm/sec	258m	1,436m	266.2m	4,595m	5,098m
6. 50cm/sec	346m	1,704m	354.0m	4,600m	5,098m

of PO mooring is smaller than that of BGC mooring. Taking into account for the characteristics of wire rope, suitable segments number should be determined for exact simulation in future.

(3) Behavior analysis of mooring systems during deployment

Behavior of mooring system during deployment was analyzed with software “behavior analysis program for Ocean Acoustic Tomography mooring system” developed by JAMSTEC and Japan Airplane, Inc.” (Shinke et

al., 1994)³⁾ in 1981 based on “lumped-mass method” by Kawadate et al.(1987, 1988)^{4) 5)}.

Tables 5 and 6 show respective parameters for simulation. Mooring system is divided each 500 m. Assuming the external forces such as wave and current velocity are negligible, behavior of mooring system during deployment was simulated (Figs. 3, 4).

After an anchor is dropped into sea surface at “anchor point”, anchor descends being pulled toward a top buoy. This motion is called as “Horizontal Return Distance

Table 5: Simulating Parameter of BGC Mooring at K-1

a) Particle	Weight in	Weight in	Cross Section	Hight	Drag	Added inertia			
	Air (kg)	Water (kg)	Area (m ²)	(m ²)	coefficient Cd	Tangental	Nomal		
Top Buoy	2558	-1360	2.97	1.8	0.5	0.1	0.1		
Instruments	392	197	5.91	9.2	1.3	0.1	0.1		
Sediment	81	40	3.25	3.5	1.3	0.1	0.1		
Sediment	83	42	3.25	3.5	1.3	0.1	0.1		
Glass Float	209	-175	10.04	8	0.5	0.1	0.1		
Glass Float	102	-89	5.02	4	0.5	0.1	0.1		
Sediment	86	45	3.25	3.5	1.3	0.1	0.1		
Glass Float	180	-810	35.14	28	0.5	0.1	0.1		
Releaser	72	68	0.78	1.9	0.7	0.1	0.1		
Anchor	2310	2145	1.04	1.3	1.2	0.4	0.4		

b) Line	Length	Size	Mass in Air	Mass in Water	Drag coefficient		Young's	Damping	Segment
	(m)	(m)	(kg/m)	(kg/m)	Tangental	Nomal	modules (kgf/m ²)	ratio D	Stp
ROPE	5	0.04	8.22	8	0.04	2.2	2.00E+04	0.04	1
ROPE	953	0.01	0.23	0.21	0.02	1.1	1.40E+04	0.04	2
ROPE	994	0.01	0.15	0.14	0.02	1.1	1.40E+04	0.04	2
ROPE	1044	0.01	0.15	0.14	0.02	1.1	1.40E+04	0.04	2
ROPE	1500	0.01	0.15	0.14	0.02	1.1	1.40E+04	0.04	3
ROPE	250	0.01	0.15	0.14	0.02	1.1	1.40E+04	0.04	1
ROPE	233	0.01	0.15	0.14	0.02	1.1	1.40E+04	0.04	1
ROPE	5	0.03	3.66	3.54	0.04	2.2	2.00E+04	0.04	1
ROPE	30	0.03	0.39	0.01	0.1	1.1	2.49E+01	0.04	1

Table 6: Simulating Parameter of PO Mooring at K-1

a) Particle	Weight in	Weight in	Cross Section	Hight	Drag	Added inertia			
	Air (kg)	Water (kg)	Area (m ²)	(m ²)	coefficient Cd	Tangental	Nomal		
Top Buoy	2569	-1349	2.97	1.8	1	0.1	0.1		
Glass Float	52	-143	7.53	0.4	1	0.1	0.1		
Glass Float	102	-687	35.14	0.4	1	0.1	0.1		
Releaser	72	68	0.78	0.4	0.7	0.1	0.1		
Anchor	2310	2145	1.04	1.3	1.2	0.4	0.4		

b) Line	Length	Size	Mass in Air	Mass in Water	Drag coefficient		Young's	Damping	Segment
	(m)	(m)	(kg/m)	(kg/m)	Tangental	Nomal	modules (kgf/m ²)	ratio D	Stp
ROPE	4525	0.02	0.25	0.08	0.1	1.1	1.40E+04	0.04	9
ROPE	460	0.02	0.25	0.08	0.1	1.1	1.40E+04	0.04	1
ROPE	5	0.03	3.66	3.54	0.04	2.2	2.00E+04	0.04	1
ROPE	30	0.03	0.39	0.01	0.1	1.1	2.49E+01	0.04	1

(HRD)". HRD (between anchor dropped point and actual anchor landing position on the sea floor) were calculated to be 674.0 m and 771.3 m for K-1 and K-3 BGC mooring systems, respectively, and 591.8 m and 662.4 m for K-1 and K-3 PO mooring systems, respectively. The difference of HRD between BGC and PO mooring systems are likely attributed to the difference in hydrodynamic resistance caused by instruments. The longer HRD at station K-3 is likely attributed to a deeper water depth and longer mooring system. Although this computation assumes that mooring systems during deployment is kept straight and ignores the external force and ship speed of approximately 1 knot, it could be expected that

HRD was approximately 12 – 14 % of lengths of mooring systems. Therefore we dropped an anchor at approximately distance of 10 % of mooring system length after we passed over a "target position".

3. Preparation

A water depth of mooring point is approximately 5,000 m. In order to locate a top buoy at 30 m, accuracy of the length of mooring system should be less than 0.1 % taking the extension under high tension into account. Efforts were made in lowering errors from an echosounder, mooring position and wire elongation as much as possible.

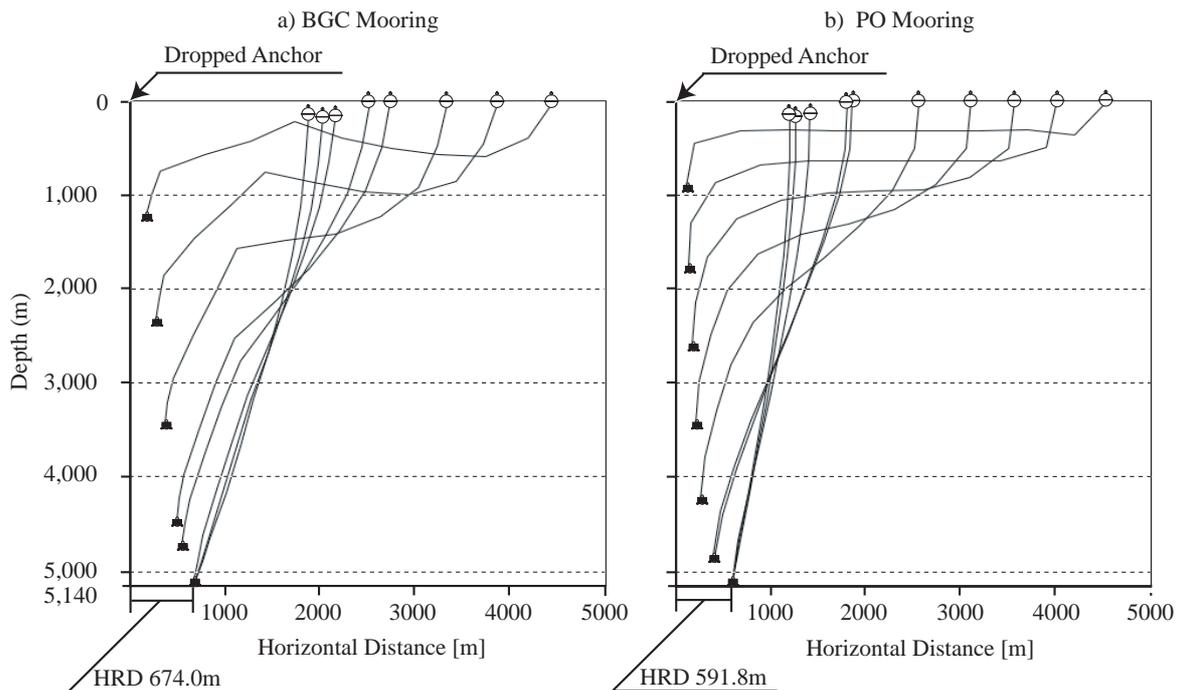


Figure 3: Result of Mooring Deployment simulation program at K-1

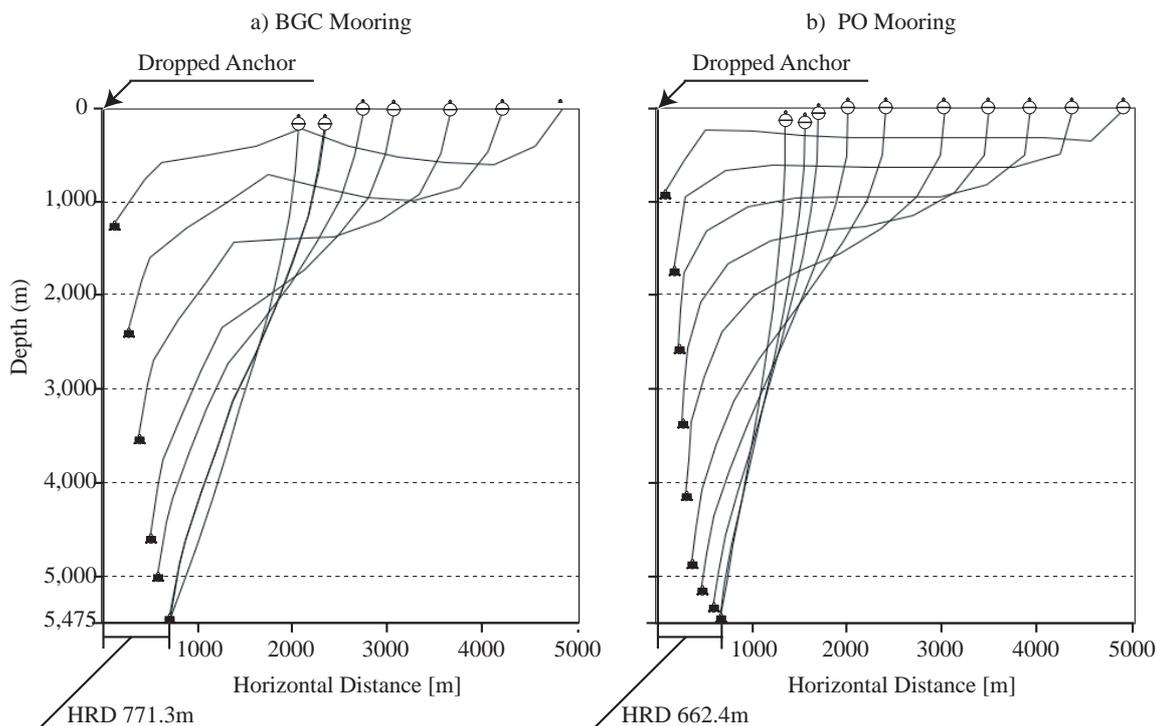


Figure 4: Result of Mooring Deployment simulation program at K-3

3.1 Press work of wire rope terminal

A wire rope terminal was self-made by using “a wire rope lock machine” (Photo 1). A wire rope terminal consists of a galvanized eyebolt and a flexible plastic cover called “boot” (Fig. 5). A “boot” plays a role in reducing bending stress on terminal (Photo 2). After a

press work of wire terminal is completed (for certification of its safety), a wire terminal is stretched with 66 % of safe working load by using stretch machine (Fig. 6). This “wire rope lock machine” can work for different wire types (5/16” and 1/4”) with using different “dices”.

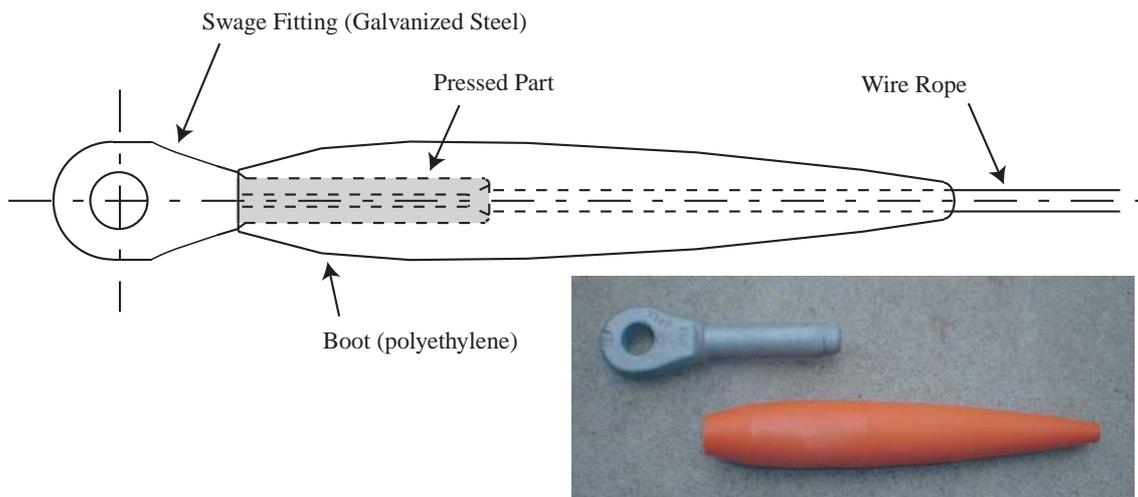


Figure 5: Wire Rope End



Photo 1: Wire Rope Lock Machine



Photo 2: Wire Rope End

3.2 Pre-stretch work

Even if a wire rope is designed and produced based on its specification, some error occurs because of mechanical and human error. In addition, wire and nylon ropes are stretched under high tension. Therefore lengths of all wire and nylon ropes used for mooring system should be measured under high tension on land. This working process is called as “pre-stretch work”. At first, a wire rope is stretched with tension of approximately 1,300 kgf that is a load on mooring system when an anchor descend to the sea floor. Sequentially, tension of 800 kgf that is average load on wire ropes is loaded

and its length was measured.

For pre-stretch work, following heavy equipments are needed (Fig. 7).

- 1) 20 ton semi-truck × 1
- 2) 10 ton truck × 1
- 3) Bulldozer × 1
- 4) Power shovel × 1
- 5) Power generator (three phase AC 220V) × 1
- 6) Tension meter (5 ton) × 1
- 7) Electronic distance meter × 1
- 8) Wire rope winding machine × 1

Pre-stretch work should be conducted at the place where a wire rope of 500 m is extended and trailer and power shovel can move around. In addition, this place should be sequestered from human habitation for safety. Moreover it should be nearby from Mutsu Institution for Oceanography to load and offload all equipment in the daylight. After investigation, a meadow located in Aomori prefecture (Fureai Grand Farm) was selected.

Pre-stretch working procedure is as follows:

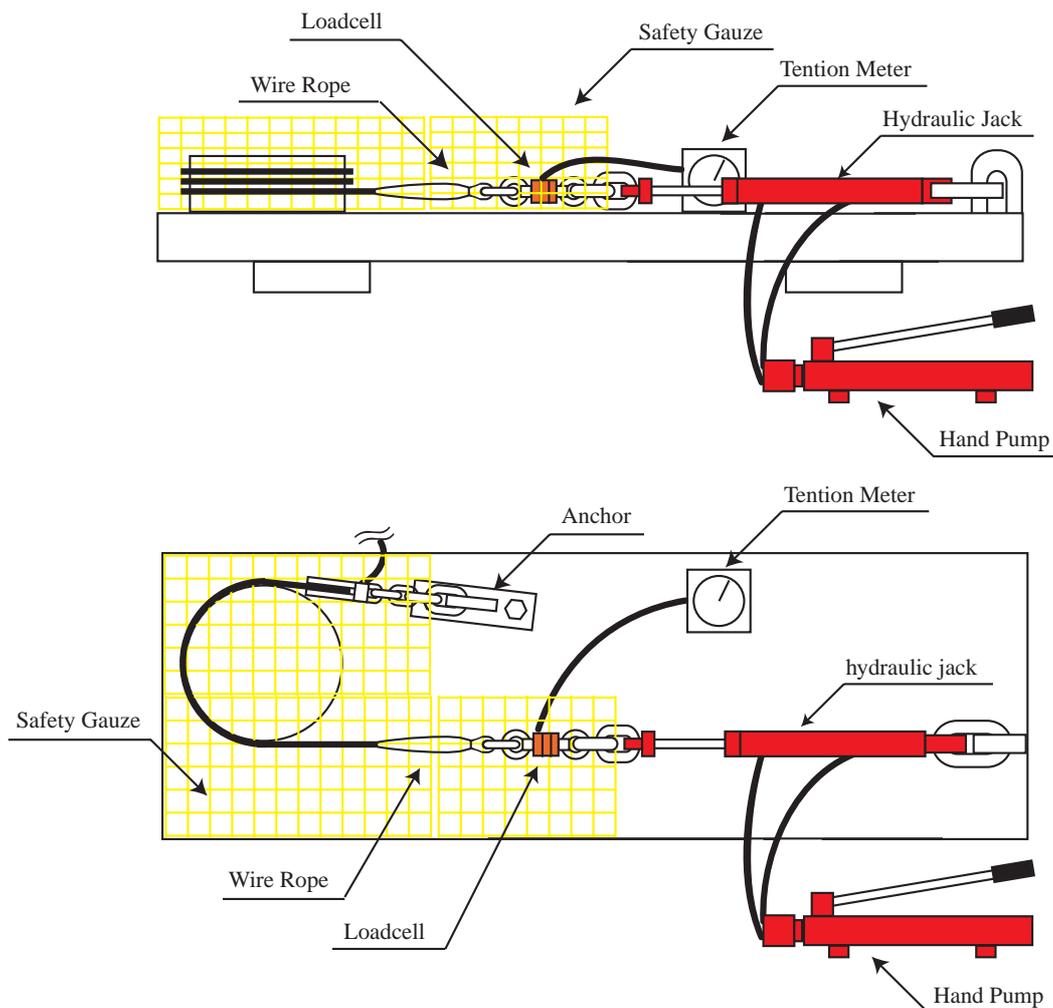


Figure 6: Wire Rope Test Stretch Machine

- (1) A 20 ton semi-truck is fixed with handbrake and wheel stoppers.
- (2) A top of wire rope is pull out from a winding real fixed on semi-truck by a bulldozer and introduced to a power shovel.
- (3) Both ends of wire rope are fixed at a semi-truck and a power shovel.
- (4) The power shovel car pulls a wire rope and tension of 90 kgf, 1,300 kgf and 800 kgf, in turn, is loaded on a wire rope.
- (5) At tensions of 90 kgf and 800 kgf, lengths of wire ropes are measured by using an electronic distance meter. The former and later are regarded to as lengths of wire rope without and with mooring tension, respectively.
- (6) After measurement, the extended wire rope is re-winded by power generator. Other winding real with wire rope is fixed on semi-truck and wire ropes of 4,500, 500, 200, 100 and 50 m are pre-stretched following the above procedure.

3.3 Result of pre-stretch

In this report, lengths of wire ropes under different situation are defined as follows:

Order length (OL): length of a wire rope that we order to a maker or we make initially.

Real length (RL): length of wire rope when wire rope is stretched with low tension of 90 kgf. This length is regarded as real wire length without tension.

Pre-stretch length (Pre): length of wire rope when wire rope is stretched with tension of 800 kgf which is average load on wire ropes (see Table 1 and 2). This length is regarded as wire length during mooring and the final mooring system is designed with Pre.

Table. 7 shows OL, average of RL, difference of RL and OL, average of Pre, difference of Pre and RL and standard deviations of differences. It is hard to estimate Pre-stretch length from only OL for difference of OL and RL is grand value. Even compare with RL and Pre, differences are $1.2 \text{ m} \pm 0.36 \text{ (SD)}$ at 500 m which is used frequently and $8.3 \text{ m} \pm 1.4 \text{ (SD)}$ at 4,500 m.

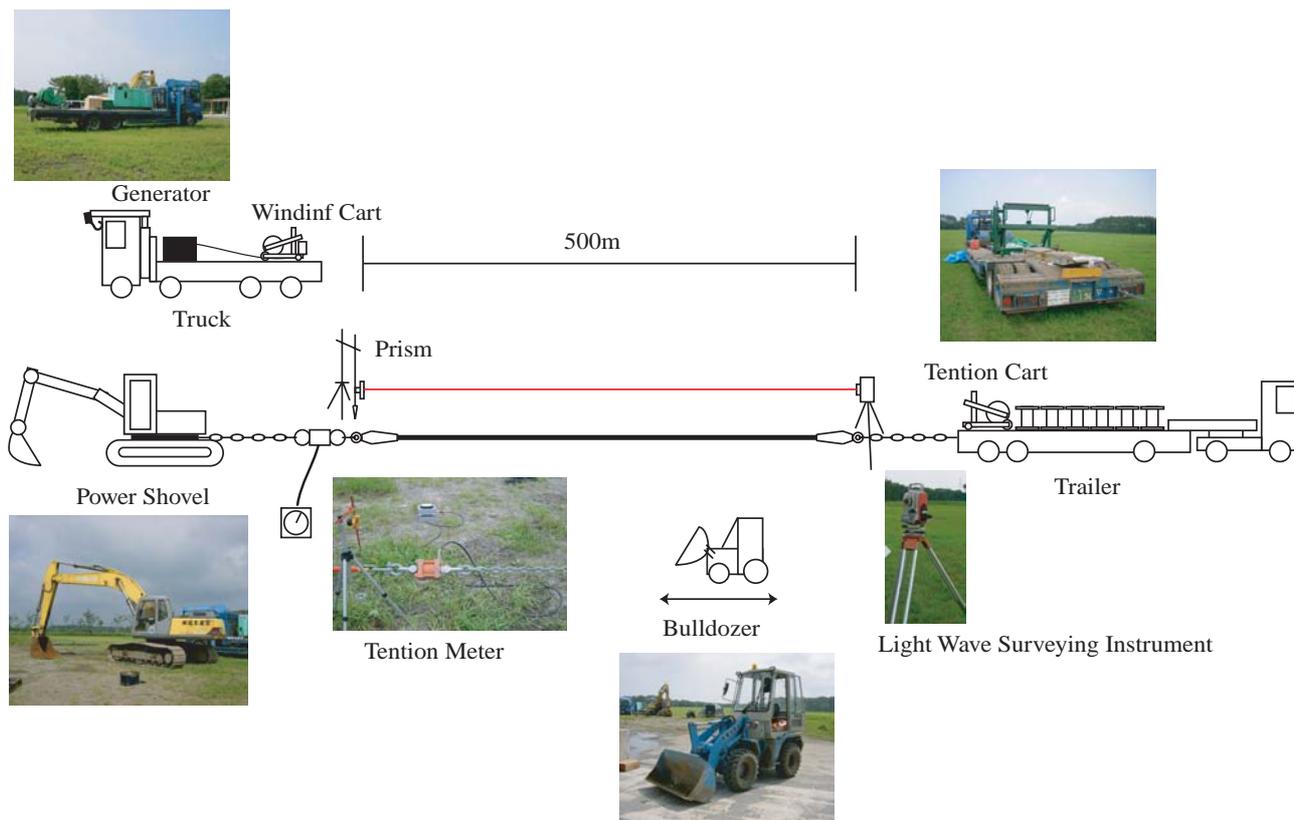


Figure 7: Wire Stretch Working Summary

Table 7: Order Length (OL), Average Real Length (RL), Average Pre-Stretch Length (Pre) and difference of RL-OL and Pre-RL in the Pre-Stretch Working

OL (m)	n	RL (m)	RL-OL (m)	±	Pre (m)	Pre-RL (m)	±
4500	2	4507.62	7.62	2.97	4515.92	8.30 (0.18%)	1.40
500	36	499.03	-0.97	1.08	500.24	1.21 (0.24%)	0.36
417	15	416.11	-0.79	1.29	416.95	0.84 (0.20%)	0.31
200	18	199.24	-0.76	0.32	199.72	0.48 (0.24%)	0.14
100	15	99.74	-0.26	0.07	100.06	0.32 (0.32%)	0.03
50	28	49.94	-0.06	0.16	50.08	0.14 (0.28%)	0.06

Therefore all wire ropes should be pre-stretched to improve the depth of instruments.

4. Deployment work of mooring system

4.1 Determination of target point

There is no point in that a precise length of mooring system is measured if water depth of target point is not measured accurately. In addition, it is impossible to install a mooring system on the target point decide previously and, therefore, a sea floor with flat area of approximately 1 mile radius should be found. Therefore the water depth and ambient bottom topography should be measured precisely. Bottom topography was measured by using a multi narrow beam echo sounding system (SeaBeam 2112.004) installed on R/V Mirai (Fig. 8 and 9). Official measurement error of SeaBeam was still

± 0.5 % even after correction of sound velocity with *in situ* temperature and salinity. It corresponded to 50 m at an area with 5,000 m water depth and is problematic for our mooring system. Instead of SeaBeam, precise water depth was measured with an altimeter (Datasonics PSA900D) installed on the multiple water sampling system with CTD (CTD / CMS). Taking into account for a ship motion, measurement of water depth by the altimeter was conducted several times at several points and final target position was decided. As long as time-series observation with mooring system was continued, we deploy mooring system aiming this target point.

4.2 Deployment procedure

(1) Start position

Essentially the deployment work of mooring system

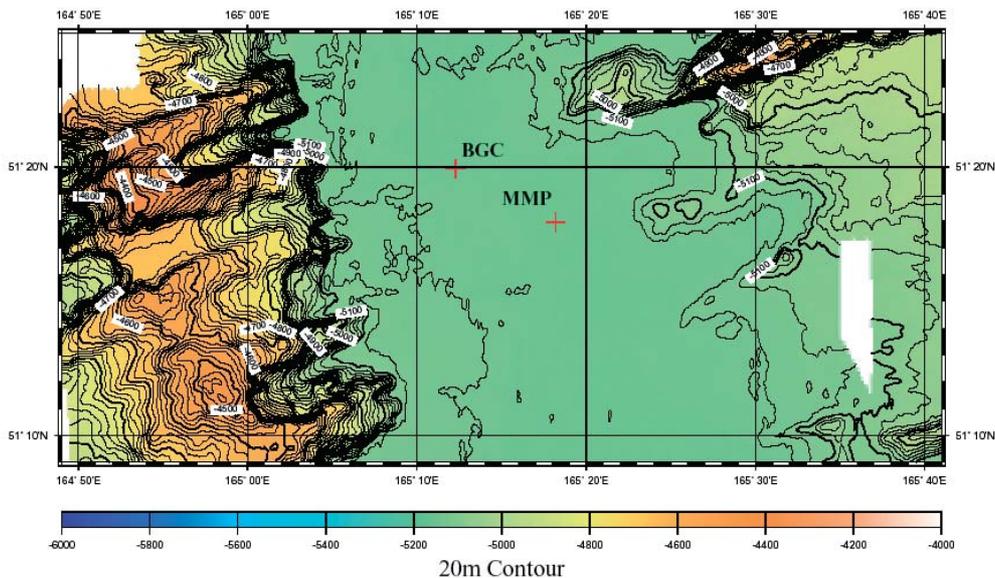


Figure 8: Sea-Beam at Station K-1 from MIRAI MR02-K05 Leg.2 Cruise Report

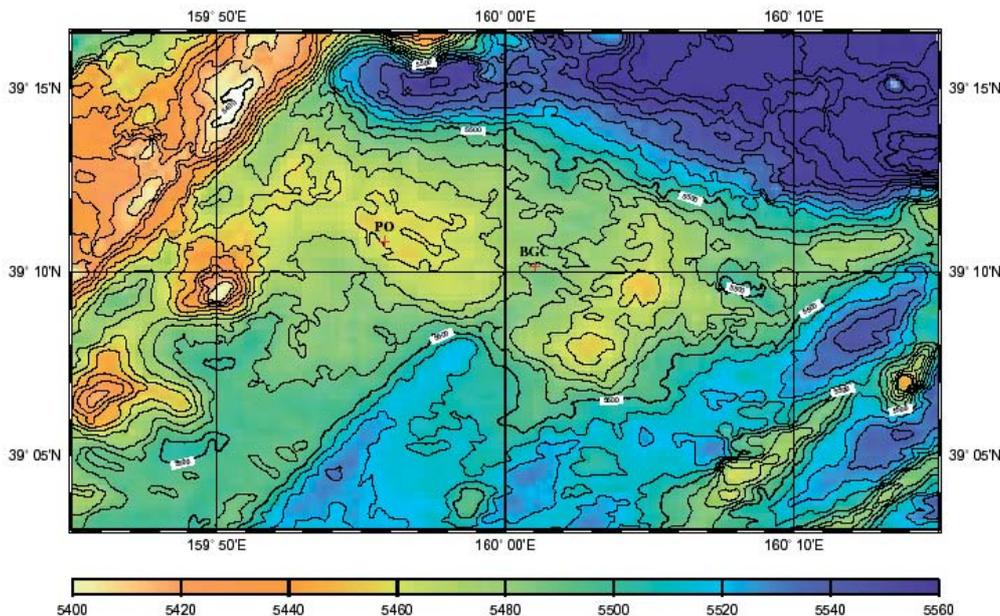


Figure 9: Sea-Beam at Station K-3 from MIRAI MR02-K05 Leg.2 Cruise Report

starts, in other words, a top buoy is dropped approximately 7 miles short of anchor drop point. After a group of grass balls just above a releaser system is dropped, mooring system is towed for approximately one hour in order to make mooring system straight.

(2) Ship speed during deployment

Ship speed relative to water is zero when a top buoy and a series of instruments (SID, RAS, WTS and ZPS) are deployed into the sea. After this step, ship speed is increased to 1 knot extending main wire rope for BGC mooring. Although too much tension on mooring system should be avoided, it is cautioned that slack of wire rope

is never caught by ship screw. For PO mooring, ship speed during deployment is 1.5 knot after a top buoy is deployed. This speed is kept until anchor is dropped and, however, sometimes adjusted up to 2 knot depending on tension of mooring system and sea condition.

(3) Ship heading

Essentially ship heading is set to upwind during deployment. However ship heading is changed in order to keep mooring system straight.

(4) Extension of main wire and nylon ropes

Extension of main wires and nylon ropes should be watched carefully verifying its tension, and adjustment

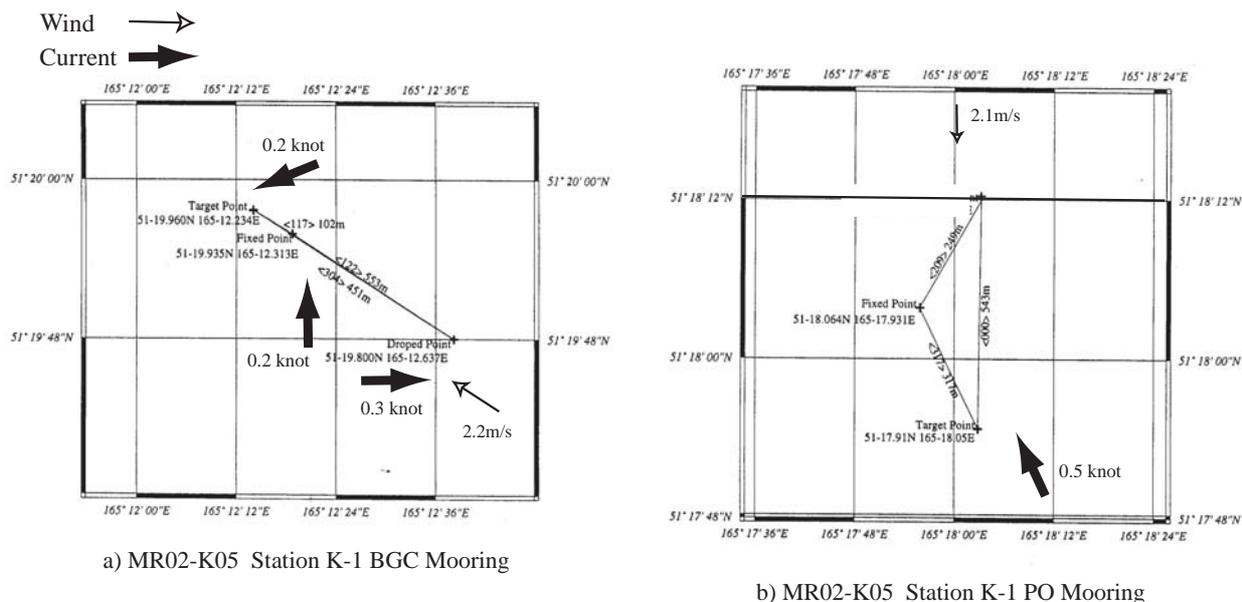


Figure 10: Mooring Fixed Point and Dropped Anchor Point at K-1 from Akamine (2002)⁽⁶⁾

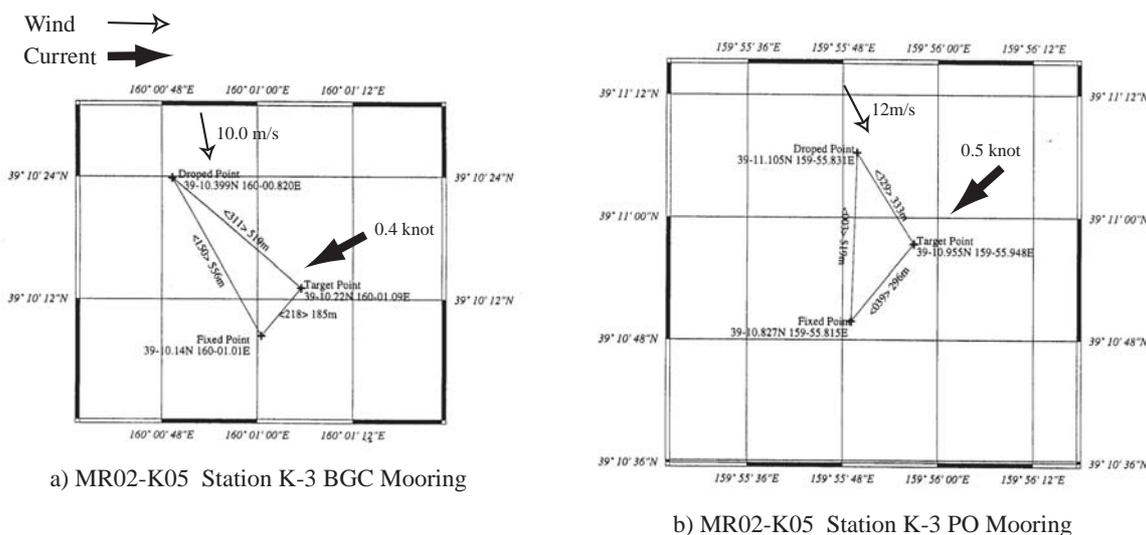


Figure 11: Mooring Fixed Point and Dropped Anchor Point at K-3 from Akamine (2002)⁽⁶⁾

of tension on mooring system is conducted by rotation speed of winch drum. When terminals of wire rope and nylon rope are connected with other ones, wire ropes is certainly anchored to a cleat on board and tension of mooring system is loaded on this. After a terminal is released from tension, connection is conducted. Groups of glass balls are deployed one by one with two safety ropes.

(5) Anchor drop

Based on results of simulation, an anchor is dropped approximately 10 % of length of mooring system after we passed through target position. An anchor is hung up 0.1 mile short of anchor dropped point and timing of anchor drop is counted down.

(6) Verification of a top buoy submersion under water

After anchor is dropped, we are back to a start point along a cruise truck and we certify that a top buoy disappears (sinks). Usually it takes approximately 1 hour for top buoy to disappear.

(7) Positioning

After a top buoy disappears, we determine a mooring point (fixed point). From 4 – 6 points on the circumference with a radius of 1 mile centering an expected fixed point, a transducer is hung down and slant range between a releaser and a transducer is measured.

(8) Record

In order to refer the next deployment or check deployment procedure, it is recommended that serial

Table 8: Loading Result of used Mooring Line

Material	Size (inch)	Official Working Load Limit (tf)	Official Minimum Braking Load (tf)	Braking Load (tf)	Existence ratio (%)	Braking Extention ratio (%)
Wire Rope	1/4	2.3	3.06	3.26	106.50	7.0
Wire Rope	1/4	2.3	3.06	3.38	110.50	4.0
Wire Rope	1/4	2.3	3.06	3.42	111.80	3.2
Wire Rope	1/4	2.3	3.06	3.38	110.50	4.4
Wire Rope	1/4	2.3	3.06	3.35	109.50	3.8
Wire Rope	1/4	2.3	3.06	3.37	110.10	4.4
Wire Rope	1/4	2.3	3.06	3.17	103.60	3.3
Wire Rope	1/4	2.3	3.06	3.18	103.90	4.2
Wire Rope	1/4	2.3	3.06	3.27	106.90	4.2
Wire Rope	5/16	3.5	3.06	5.56	119.10	4.2

Material	Size	Official Working Load Limit (tf)	Tested Load (tf)	Transform
Chain	3/4	4.8	6.1	None
Chain	3/8	3.0	6.1	None
Chain	1/2	5.1	6.1	None
Ring	7/8	5.0	6.1	None
Ring	5/8	3.0	6.1	None
Shackle	1/2	3.0	6.1	None
Shackle	5/8	4.5	6.1	None
Shackle	3/4	6.5	6.1	None

Table 9: Result of Loading Test

Method	Detail	Maximum Load (tf)	Braking Load (tf)	Elastic Point (tf)	n	Transform
Nondestructive Testing	MT	-	-	-	25	None
	RT	-	-	-	10	None
Loading Test	Normal	-	7.1 ~ 11.7	6.0	16	None
	Repititation	-	11.3 ~ 11.5	6.0	4	None
	Wrest (Photo.3 a)	-	6.8 ~ 9.8	-	2	70% of Spec.
	Widen (Photo.3 b)	-	10.8 ~ 11.7	7.0	9	None
	Cut (Photo.3 c)	-	1.6 ~ 1.8	-	10	20% of Spec.
	Sideway (Photo.3 d)	-	12.3	-	1	None
	Tangle with Shackle (Photo.3 e)	-	11.4	-	1	None
Construction Test of cross section area	Shackle (Photo.3 f)	-	15.3 ~ 19.4	10.0	5	None
	Chain	-	-	-	4	None
Hardness Test of cross section area	Shackle	-	-	-	2	None
	Vickers Hardness	-	-	-	3	None
Tangle Test	with Shackle for 10days	1.6	-	-	2	None
	with Widen for 2weeks	2.7	-	-	1	None
Damege Test	Wrest	4.5	-	-	1	None
	Sideway	4.5	-	-	1	a Little
1/2inch Loading Test	Chain	-	2.4	-	1	10% of Spec.

numbers of instruments, time of respective work are recorded precisely.

5. Results

5.1 Deployment position

Fig. 10 and 11 show the physical relation between a target point (home base), a dropped point that an anchor was dropped from the ship and a fixed point that a mooring system was actually set (Akamine, 2002)⁶⁾. Wind direction / velocity and current direction / velocity were observed by using an anemometer and Acoustic Doppler

Current Profiler (ADCP) installed on R/V Mirai, respectively. Going upwind, we deployed a mooring system from a top buoy. On Fig. 10 and 11, current direction and velocity for respective cases are averages during deployment work while those are three representative current direction / velocity in the case of BGC mooring at station K-1. It can be seen that a fixed point was shifted depending on current direction and speed.

The distances between a target point and fixed point for BGC mooring system were 102 m and 185 m at stations K-1 (Fig. 10, a) and K-3 (Fig. 11, a), respectively.



a) Wrest



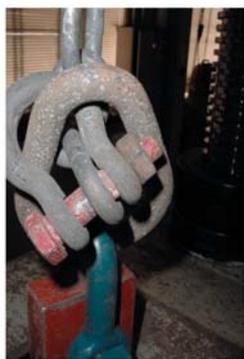
b) Widen



c) Cut



d) Sideway



e) Tangle with Shackle



f) Shackle

Photo 3: Loading Test

Those distances for PO mooring system were 317 m and 296 m at station K-1 (Fig. 10, b) and K-3 (Fig. 11, b), respectively. These corresponded to approximately 2 % for total BGC mooring system and 6 % of total PO mooring system (*ca.* 5,000 m) and less than that simulated previously (10 %. see 2.2.(3)). In future deployment, drift of mooring system by a current had better be taken into account.

5.2 Strength of used wire rope

In order to verify whether wire ropes used can be re-used or not, tensile and break test was conducted for several wire ropes with different diameters (1/4" and 5/16") used for one year deployment during September 2001 and October 2002. Wire ropes selected at random were tested and measured its extension rate and breaking force (Table 8).

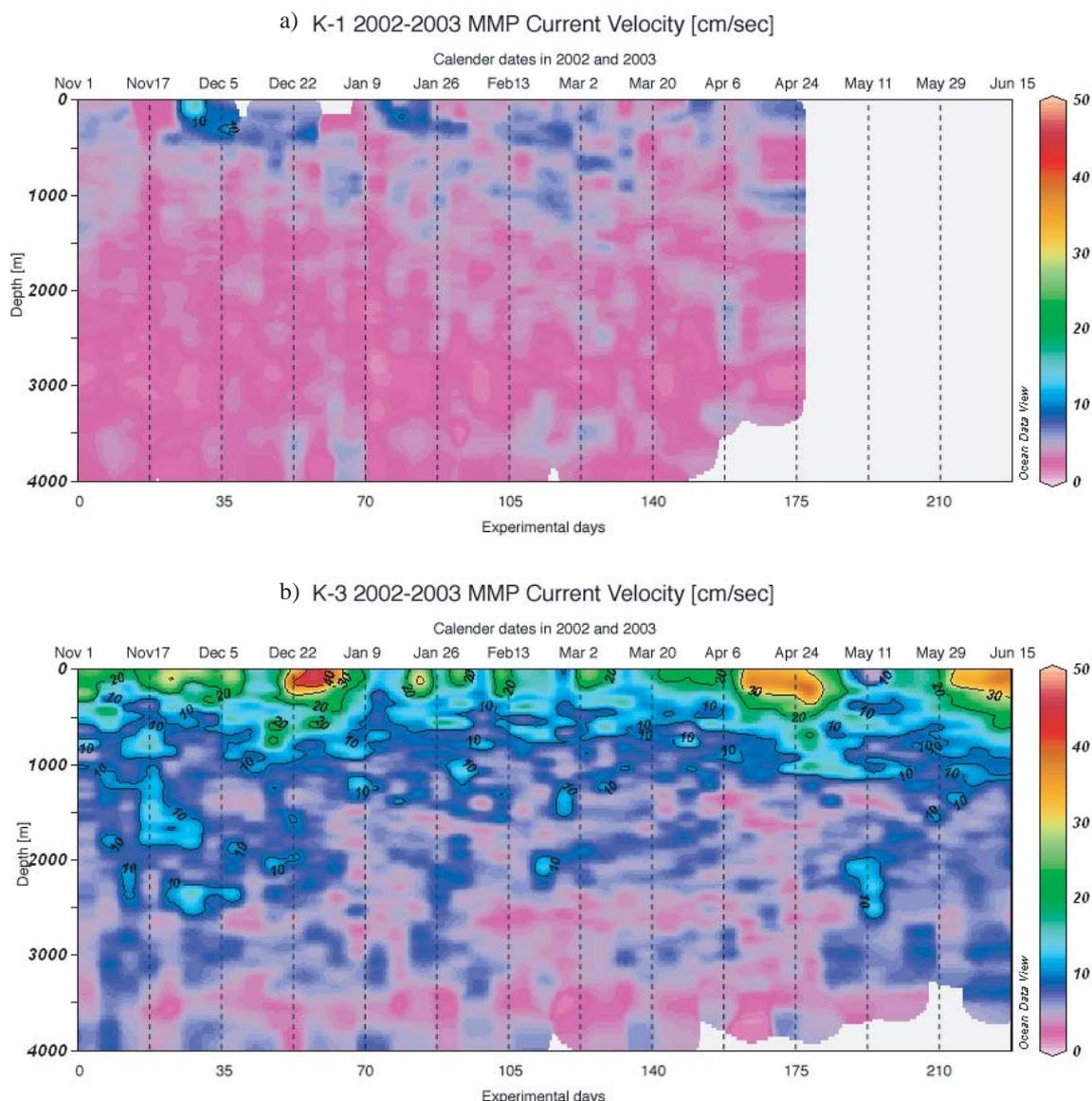


Figure 12: Current Velocity at K-1 and K-3 measured by MMP

As a result, it was verified that 10 wire ropes held initial capability. The break points of all wire ropes were their terminal connector. Simultaneously chains, shackles and rings used for deployment were also tested and showed no critical skew and crack under safety working load. Even if surface of chains, shackles and rings are oxidized, its capability after one year deployment was still kept. Therefore it was concluded that the above items could be re-used after one year deployment. However it is noted that wire ropes are usually vinyl-coated. It is difficult to detect all damages of vinyl coating from a few thousand meter's wire ropes occurred during deployment and / or recovery work. In this case, a part of wire ropes might be oxidized by water invasion and its capability might be largely lowered. This point should be taken into account.

5.3 Strength test of chain and shackle

The above test for chain and shackle is for certification of their safe working load. In order to verify their breaking load and to observe their physical change under high tension, nondestructive and destructive tests were conducted for chains and shackles used from October 2002 and October 2003.

As a nondestructive test, the magnetic particle examination and the X-ray for chains and shackles were conducted in order to detect or certify cracks, pinhole and condition of welding. In destructive test, chains under various situations such as that chains are entangled, pulled to abnormal direction, force-enlarged, oxidized and loaded for long time. Cross sections of chains before and after loading were also observed microscopically. In addition, "Vickers hardness test" that is a

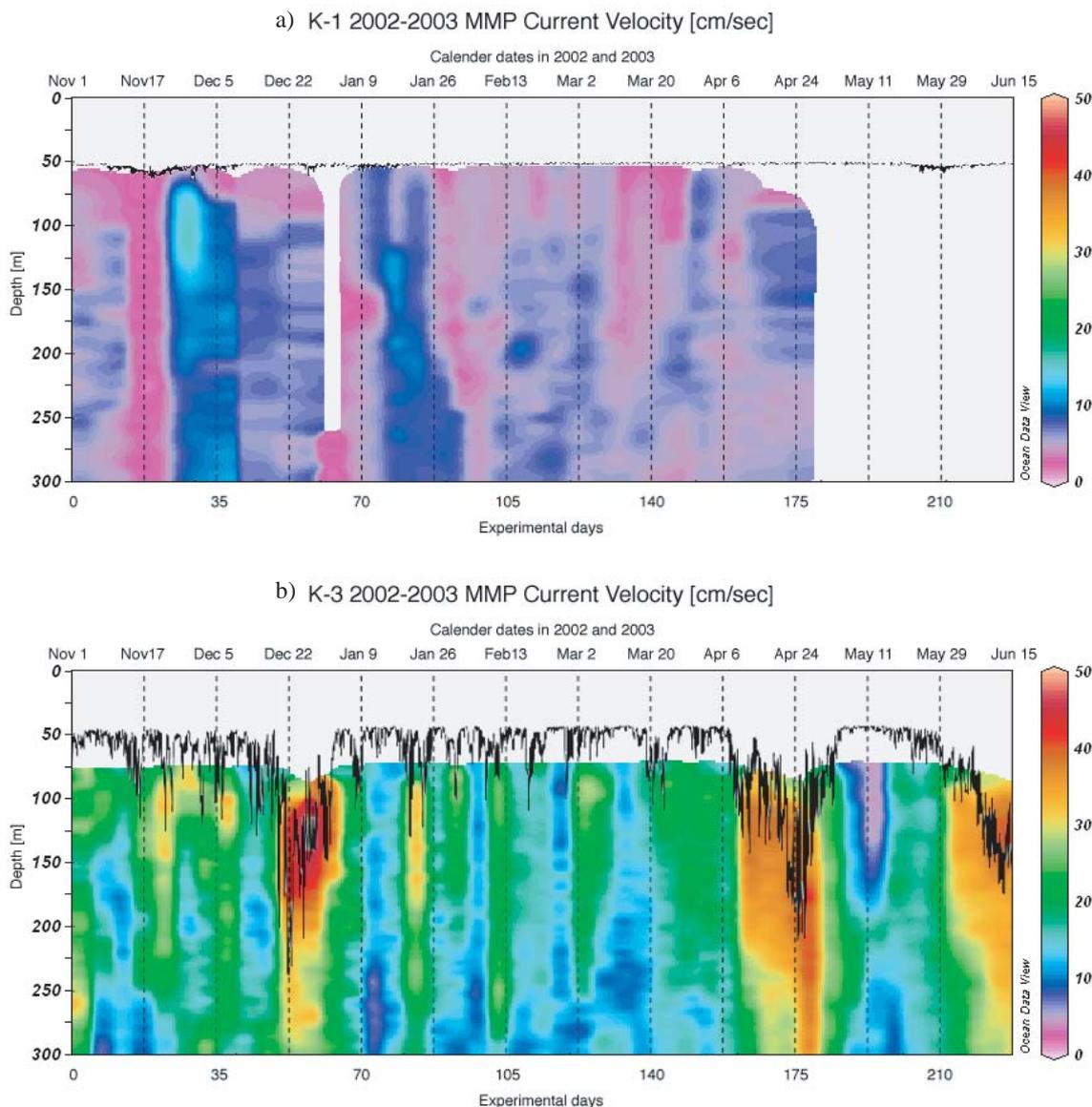


Figure 13: Comparison of Current Velocity and Depth Sensor at K-1 and K-3

measurement of crater size on chain made by press of quadrangular pyramid of diamond was carried out.

Photo 3 and Table 9 show results of nondestructive and destructive test. Based on nondestructive test, new and used chains and shackles did not show problematic damage such as abrasion, contortion and oxidation. Any problems in welding were not observed either. The yield point load of 3/8" chains was approximately 6 ton and chains were partitioned at approximately 10 – 11 ton. However yield point load of entangled chain was smaller than that of normal chain and entangled chain was partitioned at approximately 6 – 7 ton load.

5.4 Analysis of behavior of mooring system during observation

During deployment of 2002 – 2003, current direction

/ velocity and a water depth of WTS (phytoplankton sampler) were monitored by MMP and a depth sensor (RIGO DS5000), respectively.

Fig. 12 shows time-depth distribution of current velocity. At station K-1, maximum current velocity of 40 cm sec^{-1} was observed at around 100 m during November and December 2002. During this period, current velocity at around 1,000 m and below 1,000 m were 10 cm sec^{-1} and 5 cm sec^{-1} , respectively. At station K-3, between the late of December 2002 and the early January 2003, maximum velocity of 58 cm sec^{-1} was observed at around 100 – 150 m. Current velocity at around 1,000 m was 15 cm sec^{-1} and 10 cm sec^{-1} at even 2,000 m. In general, current velocity at station K-3 was larger than that at K-1.

Fig. 13 shows seasonal variability in depth of WTS

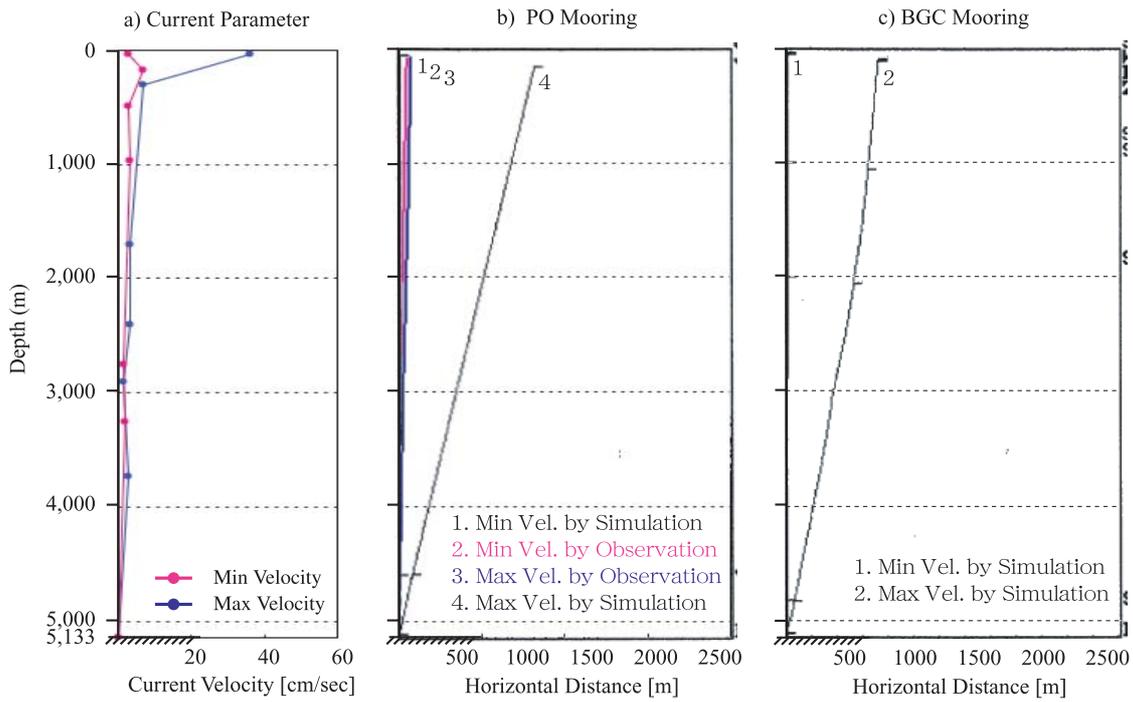


Figure 14: Comparison of MMP current velocity, statics calculation program, current velocity and Tilt at K-1

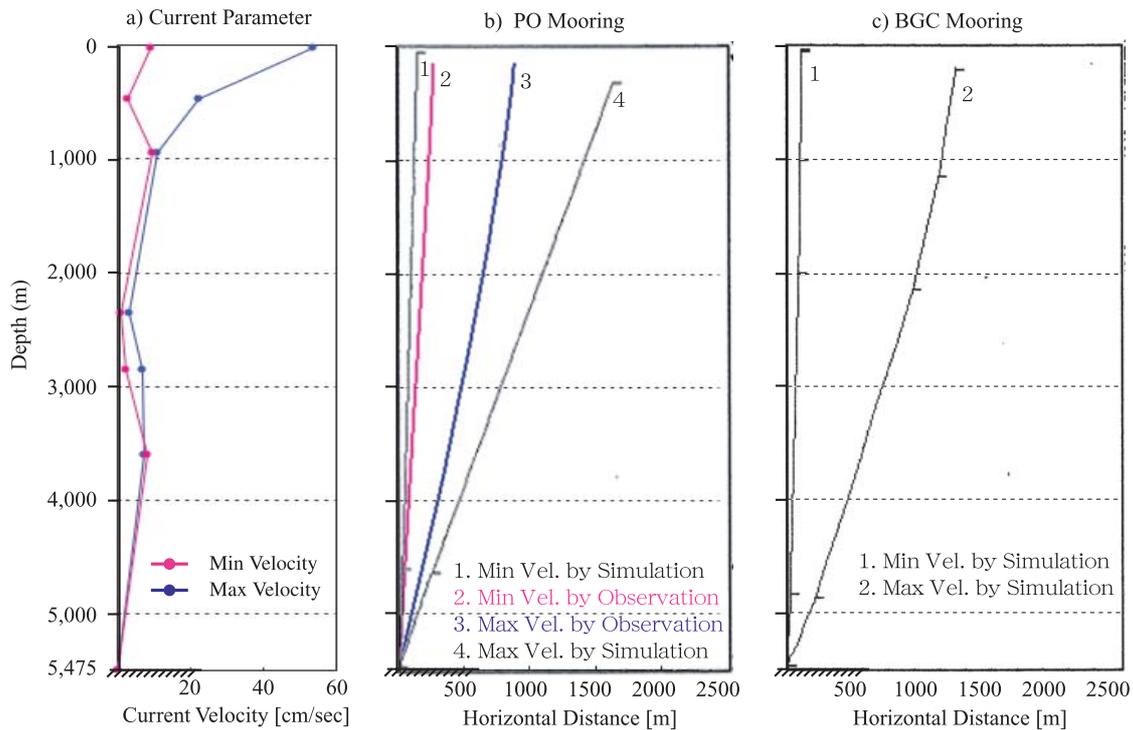


Figure 15: Comparison of MMP current velocity, statics calculation program, current velocity and Tilt at K-3

(solid line) with time-depth distribution of current velocity upper 300 m. Although PO mooring with MMP was a few km away from BGC mooring, a depth of WTS on BGC mooring was deepened when current velocity increased. Average depth of WTS at station K-1 was 60 – 70 m and relatively stable while WTS was

sometimes deepened up to more than 200 m when current velocity increased by 50 cm sec⁻¹.

Fig. 14 (a) and Fig. 15 (a) show maximum and minimum current velocity at 6 depths for stations K-1 and K-3, respectively. Assuming that these current directions are identical and using software of behavior analy-

sis (see section 2.2 (2)), tilt, water depth and tension of principal parts were re-simulated (Figs. 14 (b) (c) for K-1 and Figs 15 (b) (c) for K-3). In Figs. 14(b) and 15(b), actual tilt (or shape) of mooring systems observed by MMP are also shown.

During deployment, even when the maximum current was given, maximum inclination by simulation program has never exceeded. Especially, BGC Moorings (Fig. 14 c and 15 c) were as the simulation from only depth of WTS by depth sensor could be compared though. As for calculation not suiting at PO mooring, a current direction is considered.

6. Concluding remarks

Two types of mooring systems (BGC and PO mooring systems) for time-series observation of biogeochemistry in the northwestern North Pacific were designed, constructed with various preparations and deployed / recovered. Two years deployment for approximately 10 mooring systems revealed that a main purpose that an upper part of mooring system with time-series instruments are located within upper euphotic zone were accomplished. It was also verified that quality of materials used for mooring system was kept after 1- year deployment.

However high current velocity deepened a top buoy of BGC mooring systems by 200 m several times a year. Although correction such as current direction is required, all moorings were prediction within the limits of a simulation program.

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Although mooring masters from Woods Hole Oceanographic Institution conducted mooring work

(deployment and recovery), mooring works was never conducted successfully without enthusiastic works of ship crew of R/V MIRAI and R/V KAIREI. We also thank administrative staff of Mustu Institute for Oceanography for their support on paper works.

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