Three Years Operation of Ocean Nutrient Enhancer TAKUMI in Sagami Bay

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ABSTRACT

TAKUMI the prototype of Ocean Nutrient Enhancer, which upwells and discharges Deep Ocean Water (DOW) in the euphotic layer and increases a primary production in the sea, was set up in Sagami bay in May 2003. Since then, TAKUMI has been continuously upwelling the DOW of 100,000m3/day from the 200m depth, even in the case of rough sea condition. In this paper, the design concept and three years operation experience of TAKUMI is reported briefly. It seems that TAKUMI is the world first successful device for artificial upwelling and increasing primary production in the real sea.

KEY WORDS: Deep Ocean Water; Primary Production; Upwelling; Floating Structure; Riser Pipe; Density Current

INTRODUCTION

To increase a primary production in the sea, Upwelling and discharging a Deep Ocean Water (DOW) which has very rich nutrient salts into the euphotic surface layer has been proposed by many oceanologists as a “Fishing ground of artificial DOW upwelling” (Liu, 1999). Table 1 shows the comparison of the area and the productions in the sea in case of the ocean, the coastal and the upwelling area (Ryther, 1969). The world half fish production is made in the upwelling area which is only 0.1% of the whole sea area, for example, offshore Peru, Canary Islands, etc. But, so far, there are no successful means to make it artificially, because of the problems of the large amount of upwelling DOW, the dilution of nutrient salts in the sea, enduring the rough sea condition, the strength of very long riser pipe for upwelling, etc.

Table 1. Production in the Sea

	Sea Area		Primary Production		Fish Production	
Area	10^6 km3	Ratio(%)	10^9 tonC/year	Ratio(%)	10^6 ton/year	Ratio(%)
Ocean	336	90.0	16.3	81.5	0.16	0.07
Coastal	36	9.9	3.6	18.0	120.00	49.97
Upwelling	0.36	0.1	0.19	0.5	120.00	49.97
Total	372	100.0	20.0	100.0	240.16	100.00

MARINO-FORUM 21, a subsidiary of The Fisheries Agency of Japanese Government, established the budget of about USD 6 million and organized the research and development project to create Ocean Nutrient Enhancer (ONE for short) which upwelles and discharges DOW into the euphotic layer to increase primary production of the sea and make a fishing ground. The project started in April 2000, and the term has five years. The device was named TAKUMI. The members and their roles for the project are shown in Table 2.

Table 2. Members of TAKUMI Project

Member Company	Role
Ouchi Ocean Consultant	Project Manager
IHI Marine United	Floating Construction
JFE Engineering	Riser Pipe
Nakashima Propeller	Pump & Diesel Generator
Japan Radio Corporation	Electronic Apparatus
System Intech	Data Processing
Zenilite Buoy	Light & Signal
Mitsubishi Heavy Industries	Mooring Design
Toa Corporation	Set-up Work
Mitsui OSK Techno-Trade	Operation & Maintenance

The featuring technologies of TAKUMI as a prototype of Ocean Nutrient Enhancer are as follows.

1) Density Current Generator;
The way of rising DOW and putting it into the euphotic layer.
2) Rotational Flow in Sagami Bay;
Choice of the setting point of TAKUMI to avoid the thinning of nutrient salts.
3) Submersed Spar Type Floating Structure and Steel Riser Pipe;
Configuration of the floating structure and riser pipe to withstand against rough sea condition of the open ocean.
4) Upending;
Proper way of setting up in the actual sea.

In this paper, the above technology concept is evaluated through three years running operation of TAKUMI in Sagami Bay.

OUTLINE OF TAKUMI

The principal particulars of TAKUMI is as follows.

Total Height	abt. 213m
Maximum Breadth	16.8m
Draft (Operation)	abt. 205m
Draft(Maintenance)	abt. 185m
Displacement (Operation)	abt. 1,700t
Diameter of Riser Pipe	1.0m
Length of Riser Pipe	175m
Diameter of Column	2.5m
Diameter of Ring Nozzle	10m
Depth of Ring Nozzle	abt. 20m
Mooring System	Single Point Catenary
Depth of Mooring	abt. 1,000m
Diameter of Impeller	2.35m
Speed of Impeller	abt. 40rpm
Output of Diesel Generator (Max.)	115kw
DOW Rising Capacity	abt. 100,000m^3/day
Surface Suction Capacity	abt. 200,000m^3/day
Discharge Capacity	abt. 300,000m^3/day

The mission of TAKUMI is to rise up nutrient salts and to let them stay in the euphotic region in order to enhance the reaction of photosynthesis. If we only pump up and discharge DOW in a surface euphotic layer the mass of cold and heavy DOW descends back to the deep layer, so that we need some adjustment to avoid DOW descending. The principle of Density Current Generator which was proposed by the authors (Ouchi, et al. 1998) is the solution of letting the DOW stay horizontally in the euphotic layer as a density current. The concept and outline of Density Current Generator which makes average density water by mixing the lower and upper water and discharges it by a special impeller into the same density layer in the stratified water as shown in Fig.1.

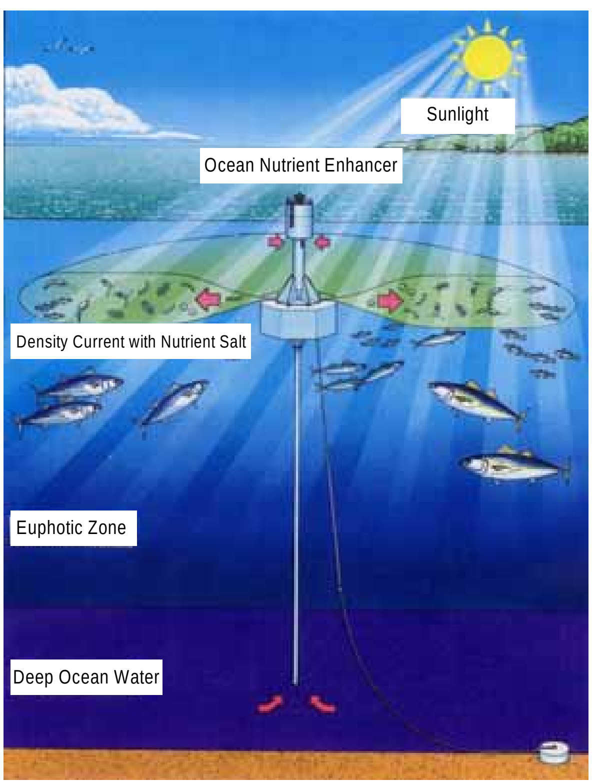

Fig .1 Outline of Density Current Generator TAKUMI

In order to make the nutrient-rich water mass efficiently and prevent the diffusion by a current, TAKUMI is scheduled to be set-up in Sagami Bay almost at the center of anti-clock wise rotational flow which is induced by strong Kuroshio stream in the southern sea area. Fig.2 shows the flow pattern in Sagami Bay (Iwata, et al. 1989). The depth of the set-up point (about 25km offshore from Hirartsuka) is about 1,000m.

The vertical profile of the water quality in summer season is shown in Fig.3. It has enough nutrient (NO3N-density) at the depth of 200m, and also has enough density stratification (almost caused by temperature stratification) of the sea water to generate density current. These two characteristics are very necessary items to operate the TAKUMI and create a fishing ground.

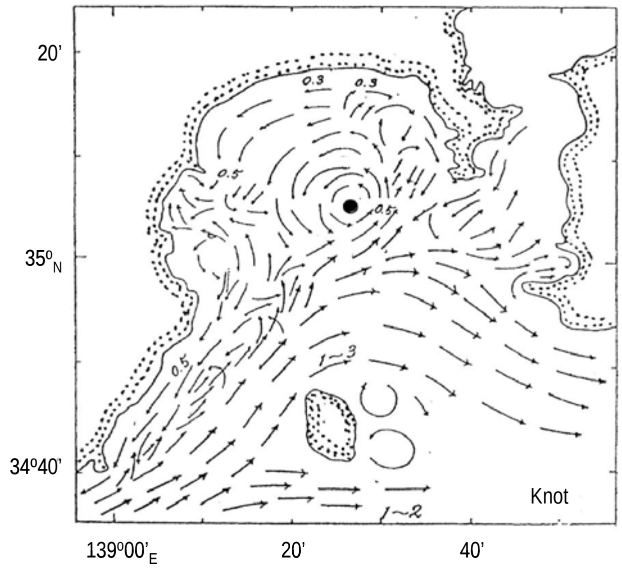

Fig.2 Rotational flow in Sagami Bay

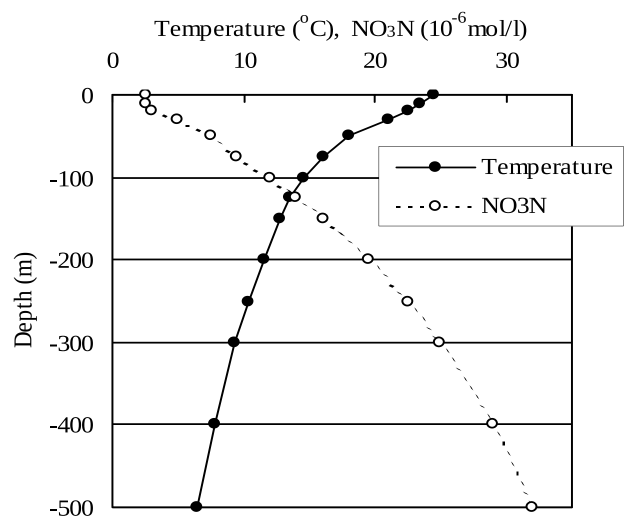

Fig.3 Water quality in Sagami Bay

The design condition at the point of set-up in Sagami Bay which is facing to Pacific Ocean is quite severe, so that the significant wave height and period are considered to be 10m and 14.9 second, and maximum wind velocity and surface current to be 50 m/s and 3.7knots (in surface layer). In this situation the submersed spar which has very

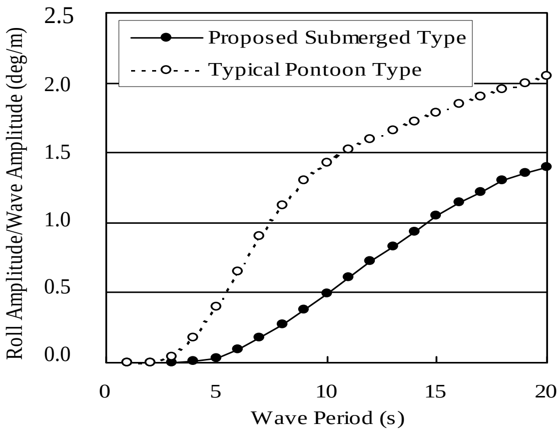

Fig.4 Rolling amplitude of floating structure

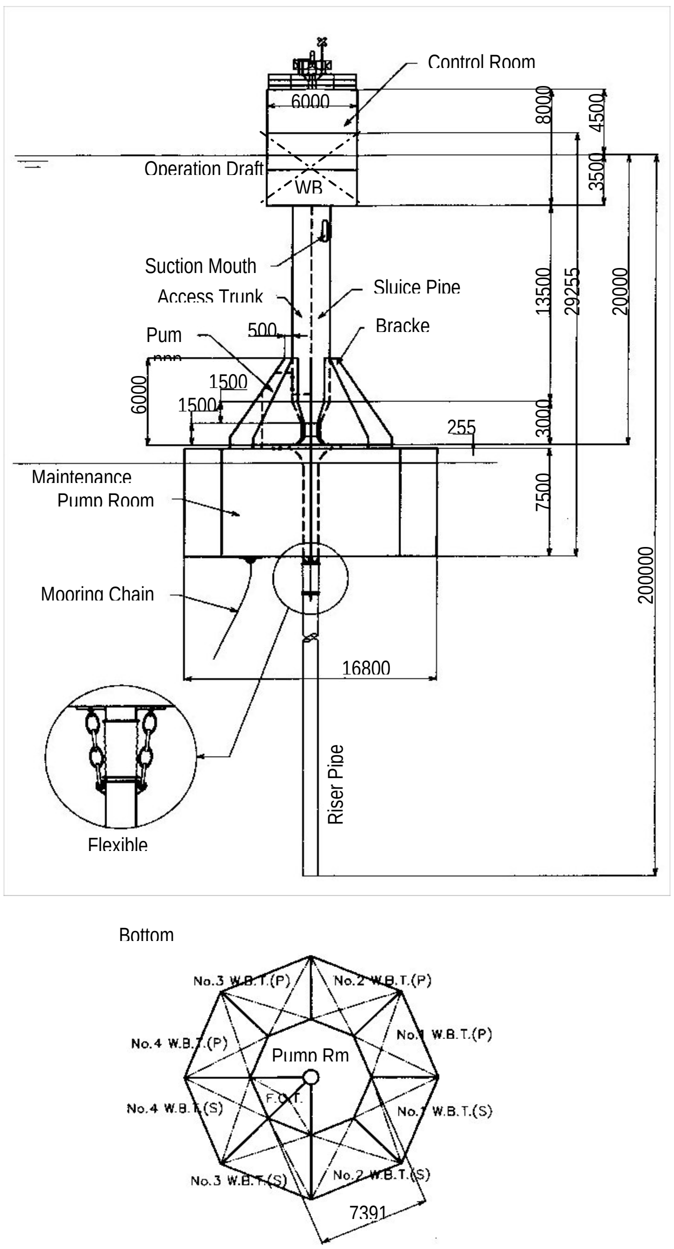

Fig. 5 General Arrangement of TAKUMI

small waterplane area and wind project area is much valuable for the purpose to reduce the motion of floating structure. Fig.4 reveals remarkable reduction of the rolling amplitude between submerged spar and conventional pontoon, calculated in accordance with 3-D singular point method (Nojiri, et al. 1980).

The advantage of very little motion of the floating structure makes good results for designing not only the strength of the floating structure but also riser pipe, mooring equipments, and all other outfittings.

Fig.5 shows the general arrangement of TAKUMI based on the provisional concept design (Ogiwara, et al. 2001). The floating structure arranges, from the upper deck to down, a control room, a water ballast tank, the column which has the sluice pipe of suction water from surface and access trunk, a discharge impeller and a ring nozzle, a pump room, water ballast and fuel oil tanks, and fixed ballast space. The impellers are composed of an upper impeller that draws surface water and a lower one that draws up DOW. The riser pipe is suspended from the bottom of the pump room by the two chains and connected with the flexible hose.

Considering the opportunities of maintenance, especially in case of regular maintenance to remove off bio-foulings of the impeller, shaft, etc, the TAKUMI rises up to the level of the discharge ring nozzle by discharging ballast water. The fixed ballast is needed to keep the floating body standing upright in case of transportation for setting up construction.

Estimation of riser displacement and strength check were carried out to make sure the reliability, using so called Marine Riser Dynamic Simulation Program (Kitakoji, et al. 1994). The other hand, the scale model testing in the experiment tank was carried out and this result endorsed the above program (Kobayashi, et.al, 2002). Fig.6 shows a sample of computer simulation result regarding displacement and bending moment of the riser in case of an irregular wave of 10m significant wave height and 10second wave period. It is known that one node vibration is occurring in this condition.

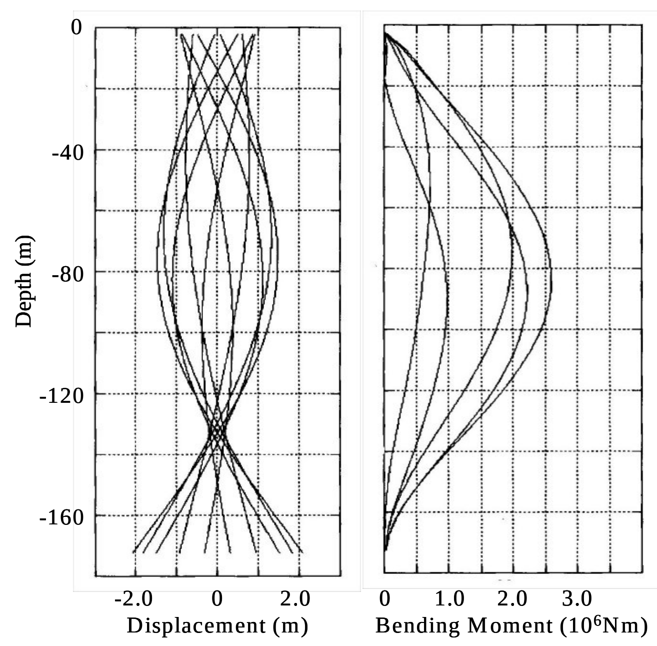

Fig.6 Displacement and bending moment of riser pipe

As to the mooring system, conventional single-point catenary mooring using wire/chain of 56mm and concrete sinker of 80tons in water is considered at the point of set-up where the depth is about 1,000m. The mooring point on the floating structure is off-center of it as shown in Fig.5. to avoid an interaction of the riser pipe and mooring chain.

Setting up operation of TAKUMI is very difficult at the open ocean such as Sagami Bay because the working ship and barge cannot work continuously owing to the high wave and strong ship motion. So that the pre-fabrication and the elimination of the onsite work such as welding fabrication etc. is highly recommended to keep the safety, reliability, and cost effectiveness for the setting up operation.

An upending, the free fall of horizontally laying riser pipe whose end is supported, and instantly making the riser pipe vertical pendant, seems to be the key technology for the setting up operation. In order to know the possibility of upending of pre-fabricated long riser pipe of 200m, a study to find the way of upending was carried out by using computer simulation (Morikawa, et al. 1992). The acceptable case which is small deflection and weak bending stress was found. From the results of such simulations, it was known that the upending is possible if the pipe is fitted with some floaters in proper position. as shown in Fig.7.

There are no upending experiences of such a long steel pipe whose inner space is filled with water. The confirmation tank test of upending using a scale model is needed to make the setting up plan for the safety operation, anyway.

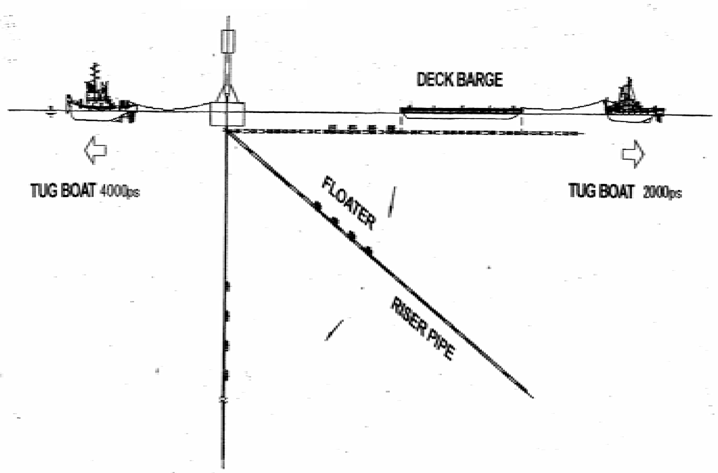

Fig.7 Upending Riser Pipe

OPERATION OF TAKUMI

After the preparation work and testing on the sea for the various kind of equipments such as Diesel Generator, Upwelling Pumps, Measurement Gauges, Electric Apparatus, etc, TAKUMI has come into continuous operation as the Ocean Nutrient Enhancer since July 18, 2003. Fig.8 shows the TAKUMI's floating structure and riser pipe in Final Docking in IHI Yokohama Shipyard, and Fig.9 shows TAKUMI working on normal operation draft at Sagami Bay (Ouchi, et. Al. 2005).

The driving system data such as the diesel engine, the generator, the motor, the impeller, etc. and the environment data such as temperature and velocity of the sea water and air, etc. are transmitted by wireless system to the land based receiver, and we can remotely watch the data on demand with the individual PC. But, as for the operation of the diesel engine, generator, pumps, valves, etc. is done only on the local site.

The maintenance policy for running TAKUMI is as follows,

・Constantly : Monitoring data in land.

・Every Month : Maintenance of filters for the diesel engine lubricating oil system on board. Fig.10 shows maintenance team boarding on TAKUMI

・Every Three Months : Bunkering of fuel oil for the diesel engine, from a bunkering barge.

Fig.8 TAKUMI on Final Docking

Fig.9 TAKUMI on operation

Fig.10 Boarding on TAKUMI

・Every Year: Inspection and maintenance for underwater apparatuses such as impeller, submerged motor, flexible joint, etc. by lifting up TAKUMI discharging the water ballast.

TAKUMI has been working more than three years since July 2003 in Sagami bay continuously (whole Year in 2003-2004, Summer Season 6 Months in 2005 and 2006), and there is no significant trouble in spite of several big typhoons. Fig.11 shows the position change of TAKUMI during October 2004. Fig.12 shows the state of the wind, wave, motions of the float and stress of the riser pipe, during 20-25 October 2004. In this term, the big typhoon No23 passed on Sagami Bay in the 21th Oct. and 3 knots strong current from Kuroshio came into Sagami Bay in the 23th Oct.

From Fig.11, the moving range of the single point mooring was very significantly changed. The distance between TAKUMI and the

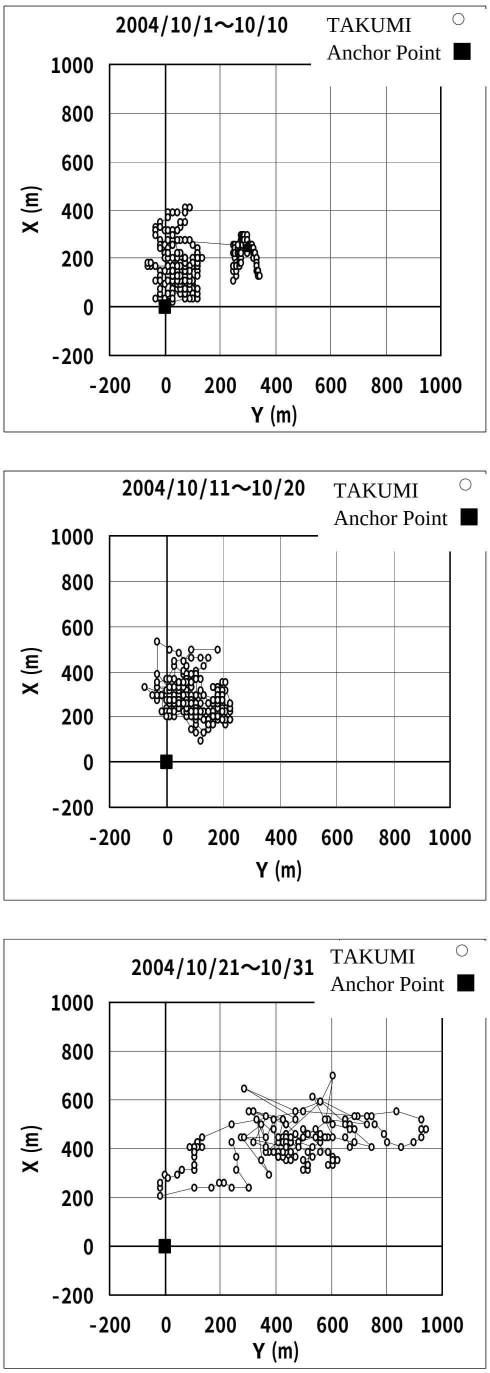

Fig.11 Position change of TAKUMI

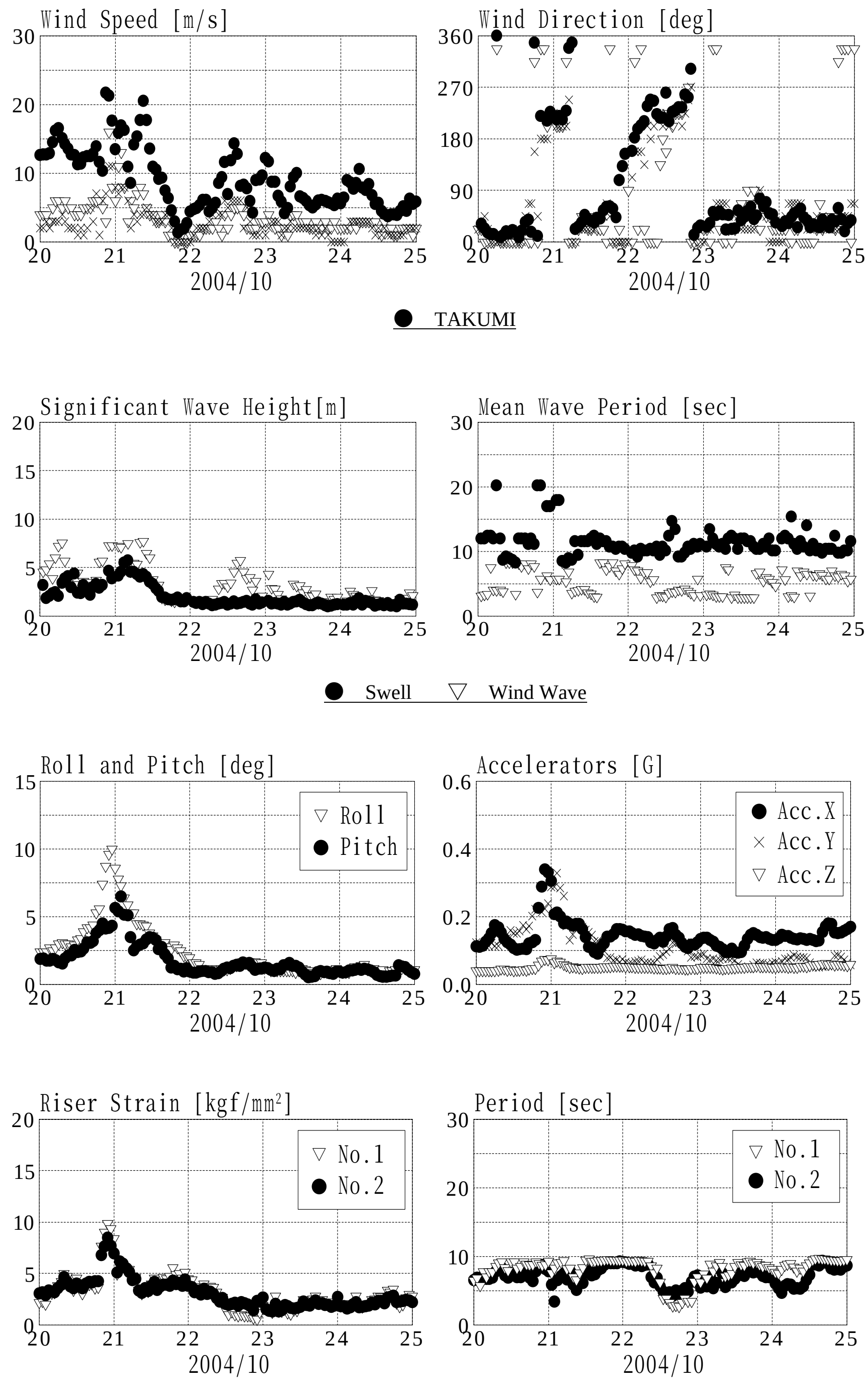

Fig.12 Data of wind, wave, motions and strain

anchor point which is usually about 200-400m is almost 1,000m because of rough sea and strong current condition.

From Fig.12, the rolling motion of TAKUMI was less than 10 $^{\circ}$ in case of about 8m significant wave height and 18 second wave period in the 21th Oct. It is almost same order which we estimated as shown in Fig.4. As for the strain of the riser pipe of about 100m depth on the same time, the stress level of less than 10kgf/mm2 was observed. It agreed with the riser pipe design.

Fig.13 shows TAKUMI lifted up to make a annual inspection work in December 2004, about 1.5 years after setting-up. Thickness of 10mm average bio-fouling is observed in the area where anti-fouling paint was not applied.

CONCLUSION

TAKUMI has been working for 3.5 years continuously in Sagami Bay, even in the rough sea state of typhoon class, and the acquisition data of the motion, strength, moving characteristics, etc. endorsed that the initial design and estimation of TAKUMI is right.

It is proved that a TAKUMI type floating structure with riser pipe and mooring system is very suitable for an offshore platform as an Ocean Nutrient Enhancer.

The biological investigation and study on the change of primary production and fish production are now being carried out around TAKUMI and Sagami Bay, by the investigation team of Kochi University, University of Tokyo, Tokyo University of Marine Science and Technology, Hiroshima University, etc. The conclusion report on the effect of TAKUMI as Ocean Nutrient Enhancer will be scheduled in March 2008.

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Fig.13 TAKUMI on the maintenance work

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