Design Concept and Experiment of Ocean Nutrient Enhancer "TAKUMI"

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***Abstract* - 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". But, so far, there are no successful means to make it, 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. The design concept of Ocean Nutrient Enhancer TAKUMI, featuring the density current for avoiding the dilution of nutrient salts, the spar type submersible floating structure for withstanding the rough sea condition, and the design and analysis of riser pipe for not only in case of rough sea but also in case of the upending which is world first challenge of election of steel riser pipe with gravity fall in the sub-sea, is introduced. Also, about one year continuous running operation of TAKUMI and the investigation results of the water mass discharged from TAKUMI are reported.**

I. INTRODUCTION

Upwelling of Deep Ocean Water (DOW), which is the seawater of more than 200m depth having very dense nutrient salts such as Nitrogen, Phosphorus, etc., can make the sea very rich fishing ground. DOW can cancell the lack of the nutrient salt in the euphotic surface layer of the sea where the photosynthesis can be done and enhance a growth of phytoplanktons as the food for fishes. The fishing ground at the offshore Peru is one of the best samples of the DOW upwelling sea [1].

Many experts are pointing out that if we can upwell the DOW artificially in the sea where there are no vertical circulation because of gravity stratification, we can create new fishing ground [2]. And this is one of the big solutions for the problem of food shortage in 21st century. But, so far, there are no practical means to make it.

MARINO-FORUM 21, a subsidiary of The Fisheries Agency of Japanese Government, have established the budget of about 1,000 million yen 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 has been started in April 2000, and the term is five years. The device was named TAKUMI. The members and their roles for the project are shown in Table 1.

A feasibility study on the requisite technologies stated as follows were carried out to establish the concept and outline of the ONE.

1) Density Current Generator;
   The way of rising DOW and putting it into the euphotic layer.

Table 1. Members and Roles for the 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
Toa Corporation	Set-up Work
Mitsui OSK Techno-Trade	Operation & Maintenance

2) Rotational Flow in Sagami Bay;
   Choice of the setting point of ONE 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 solutions of the above studies are introduced and the outline of ONE which is bran-new offshore structure is proposed.

II. DESIGN CONCEPT OF TAKUMI

A. Outline and Particulars

The conceptual outline of the Ocean Nutrient Enhancer TAKUMI proposed by the authors is shown in Fig.1, and the principal particulars TAKUMI are 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

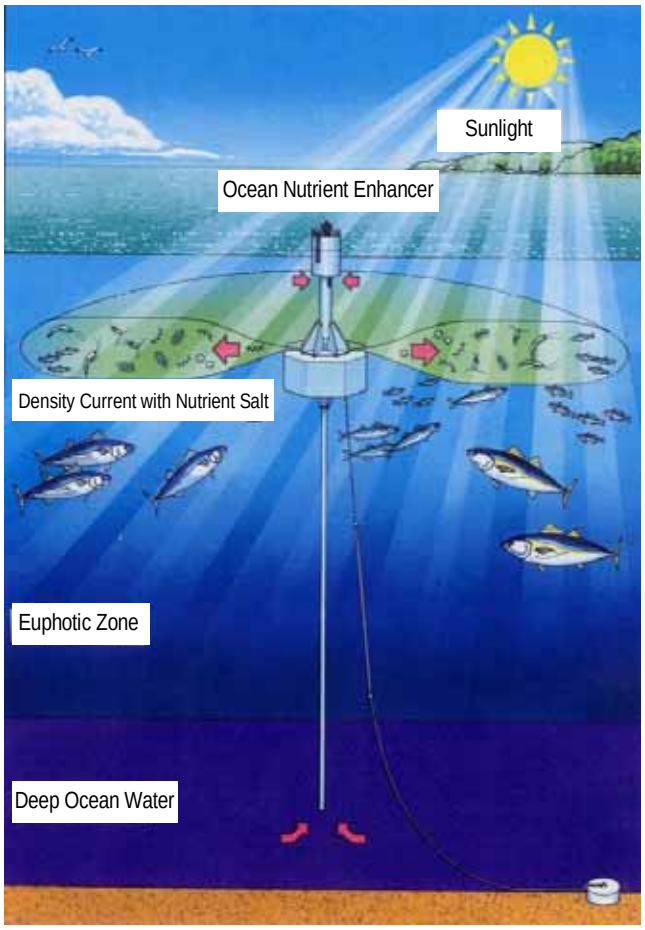

Fig.1 Outline of TAKUMI

B. Density Current Generator

The mission of the ONE 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

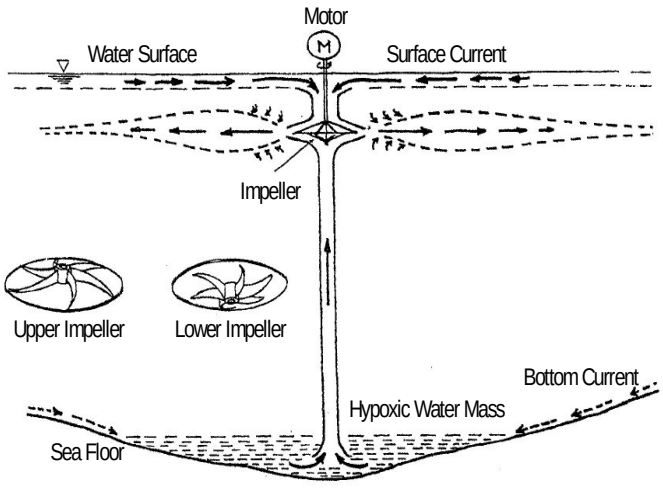

Fig.2 Outline of Density Current Generator

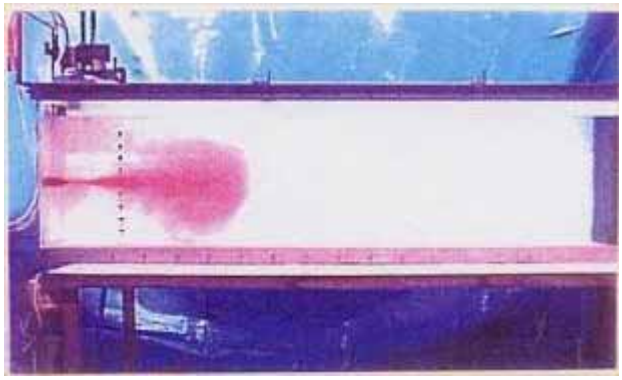

Fig.3 Discharging into Non-stratified Water

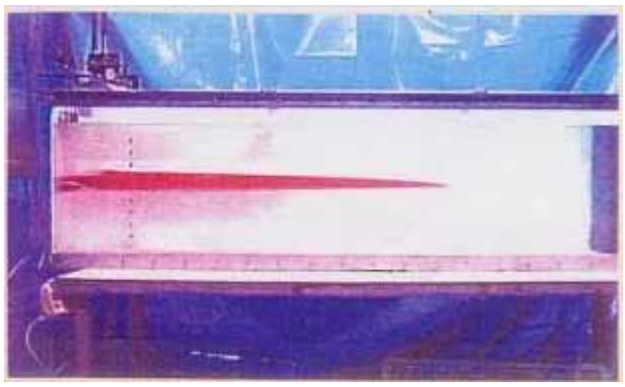

Fig.4 Density Current in 2-Dimensional Tank

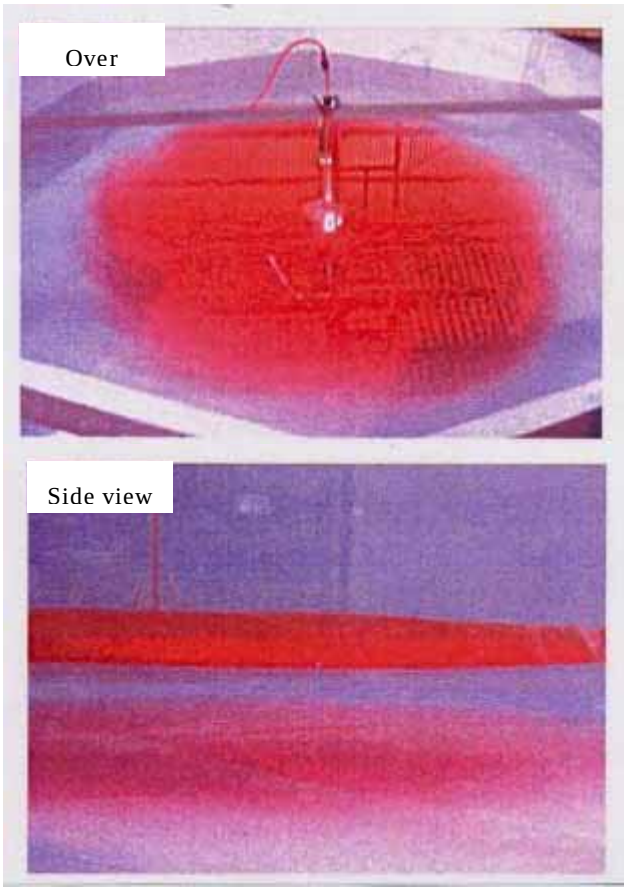

Fig.5 Density Current in 3-Dimensional Tank

principle of Density Current Generator which was proposed by the authors [3] 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.2.

To know the characteristics and behaviors of the density current in the stratification condition of Sagami Bay in summer season (Difference of water density (σt) is 3.5/1,000 between the depth 0m and 80m), the scale model test of 1/200 was carried out in the 2-Dimensional and 3-Dimensional experiment tanks [4]. No density current is observed in non-stratified water as shown in Fig.3, but horizontal density current is clearly observed in the above stratified condition as shown in Fig.4.

Fig.5 shows the behavior of density current in 3-Dimentional experiment tank in the same stratified conditions. From the law of similarity by W. Froude regarding the gravity and inertia, we can estimate that TAKUMI will make the circle of watermass with the density current whose size is about 12m thickness and 510m diameter after 14 hours from starting discharge.

C. Rotational Flow in Sagami Bay

In order to make the nutrient-rich water mass efficiently and prevent the dilution 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.6 shows the flow pattern in Sagami Bay [5]. 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.7. 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 TAKUMI and create a fishing ground.

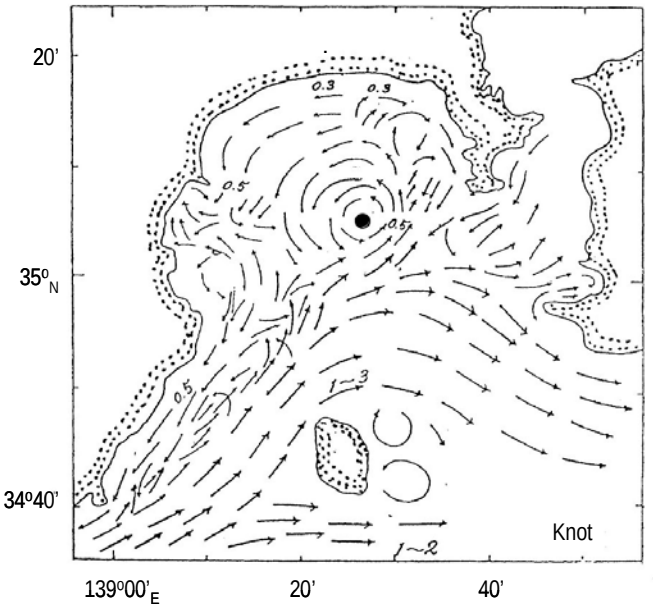

Fig.6 Rotational Flow in Sagami Bay

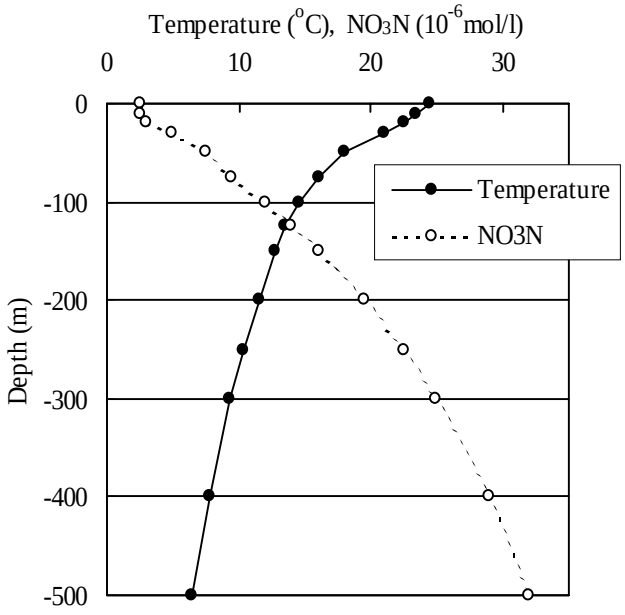

Fig.7 Water Quality in Sagami Bay

D. Submerged Spar Type Floating Structure and Riser Pipe

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 this situation the submersed spar which has very small waterplane area and wind project area is much valuable for the purpose to reduce the motion of floating structure. Fig.8 reveals remarkable reduction of the rolling amplitude between submerged spar and conventional pontoon, calculated in accordance with 3-D singular point method [6].

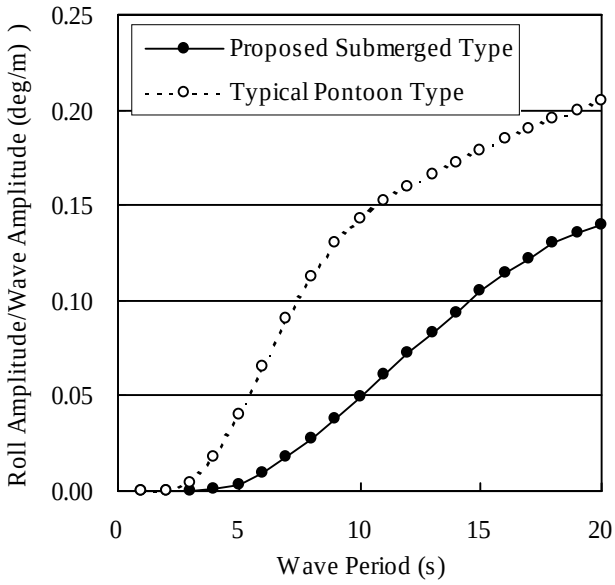

Fig.8 Rolling Amplitude of Floating Structure

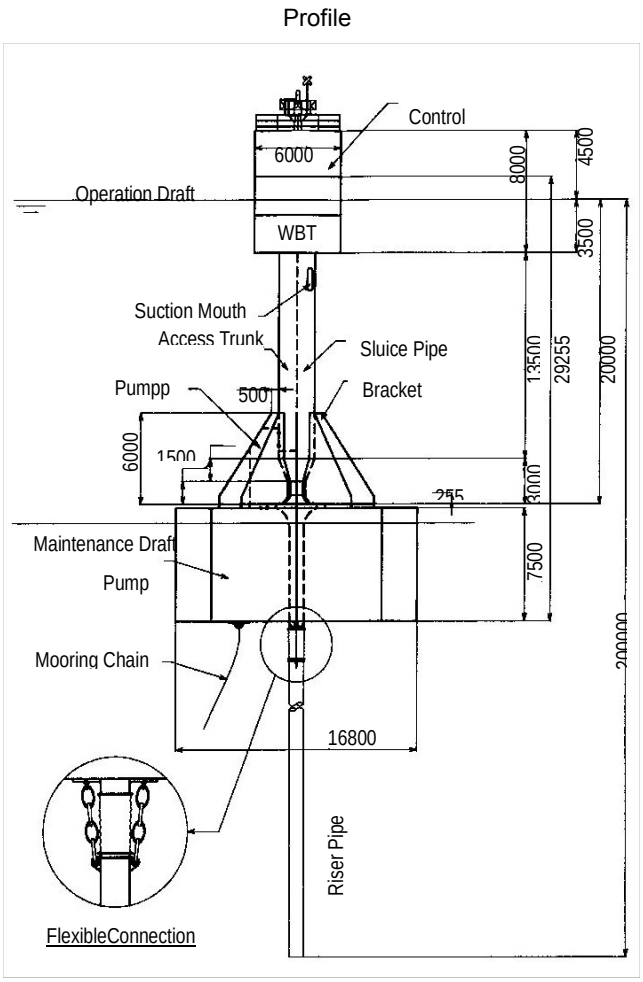

Fig.9 General arrangement of TAKUMI

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 outfitings.

Fig.9 shows the general arrangement of TAKUMI based on the provisional concept design [7]. The floating structure arranges, from the upper deck to down, the control room, the water ballast tank, the column which has the sluice pipe of suction water from surface and access trunk, the discharge impellers and ring nozzle, the pump room, the 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

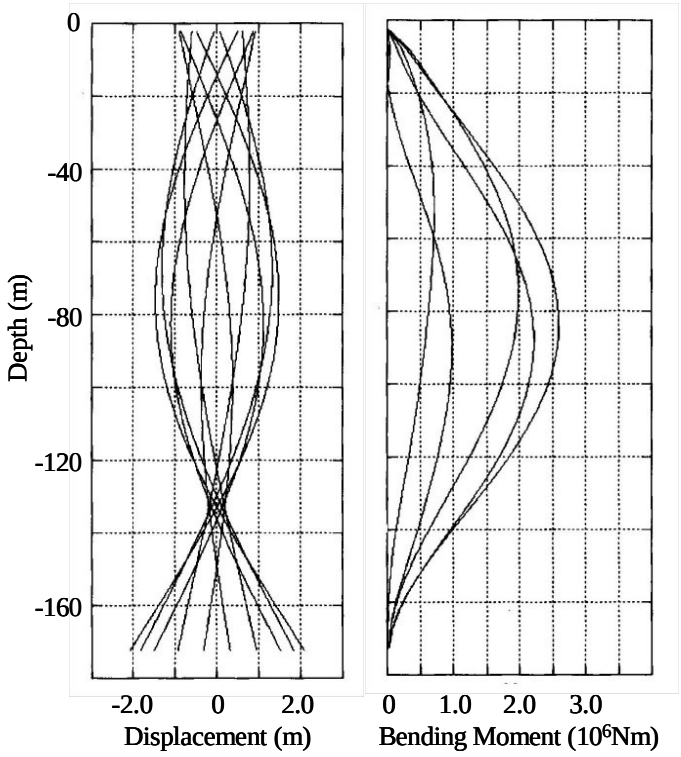

Fig.10 Displacement & Bending Moment of Riser

of the pump room by the two chains and connected with the flexible connection. Considering the opportunities of maintenance, especially in case of regular maintenance to remove off bio-foulings of the impeller, shaft, etc, the ONE 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 was carried out to make sure the reliability, using so called Marine Riser Dynamic Simulation Program [8]. The other hand, the scale model testing in the experiment tank was carried out and this result endorsed the above program [9]. Fig.10 shows the sample of computer simulation result regarding displacement and bending moment of the riser in case of the irregular wave of 10m significant wave height and 10 second wave period. It is known that one node vibration is occurring in this condition.

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.9. to avoid an interaction of the riser pipe and mooring chain.

E. Upending

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, the study to find the way of upending was carried out by using computer simulation. The acceptable case which is small deflection and weak bending stress was found as shown in Fig.11. From the results of such simulations [10], it was known that the upending is possible if the pipe is fitted with some floaters in proper position.

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 scale model is needed to make the setting up plan for the safety operation, anyway.

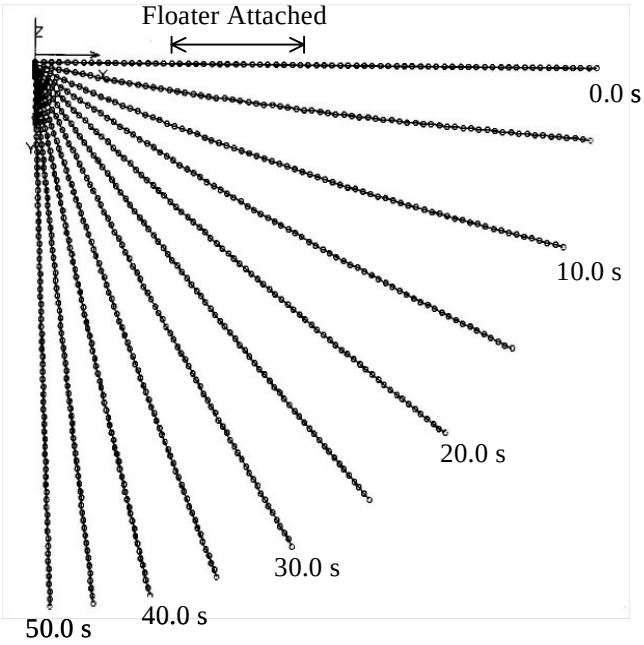

Fig.11 Computor Simulation for Upending Riser Pipe

III. EXPERIMENT IN THE SEA

A. Manufacturing and Setup

TAKUMI's floating structure which was manufactured in IHIMU Aioi works and the riser pipe which was manufactured in JFE Tsurumi works were combined, in May 2003 at the floating dock of IHIMU Yokohama works. After the final docking the set-up operation of TAKUMI at Sagami Bay including the upending operation was carried out. Fig.12 shows the picture of TAKUMI waiting undocking.

After the preparation work and testing on the sea for the various kind of equipments (Diesel Generator, Upwelling Pumps, Measurement Gauges, Electric Apparatus, etc), TAKUMI has come into continuous operation as the Ocean Nutrient Enhancer since July 18, 2003. Table 2 shows the official test results of upwelling pump performance. This shows that the pump is upwelling DOW of more than 100,000m3/day in case of 39 rpm impeller speed which is normal continuous output of electric motor.

Fig.13 shows that TAKUMI is working on normal operation draft at Sagami Bay.

Table2 Test Result Upwelling Pump

Impeller Speed	DOW Upwelling	Surfacewater Sucking	Mixed Water Discharge	Moter Power
rpm	10^3m3/day	10^3m3/day	10^3m3/day	KW
27	68	126	194	14.1
34	90	168	258	24.2
39	106	197	304	34.3
41	113	209	323	39.0

Fig.12 TAKUMI at Final Dock

Fig.13 TAKUMI Working at Sagami Bay

B. Investigation of Discharged Water Mass

It is very important to know the density of DOW which is discharged from TAKUMI, because a primary production and fish production very much depend on a density of nutrient salts which is included in DOW.

In 12th September 2003, multi-point vertical CTD (Capacitance/Salt, Temperature, Depth) measurements along the downstream current from TAKUMI was carried out to investigate the dilution of density current water mass from TAKUMI. In Sagami Bay, the salt density of surface water and DOW are rather lower than 20 to 30m depth water where the density current water mass from TAKUMI is remaining. So that, a quality of the water mass must be lower salt density at the 20 to 30m layer in the downstream of TAKUMI.

Fig.14 shows T-S (Temperature-Salt) Diagram obtained from the multi-point vertical CTD measurements in the downstream of TAKUMI. The red lines show the reference point on upstream side. Fig.14 shows that the water mass from TAKUMI is lower salt density and a quality of the water mass is almost same and not so much diluted even 3km downstream from TAKUMI.

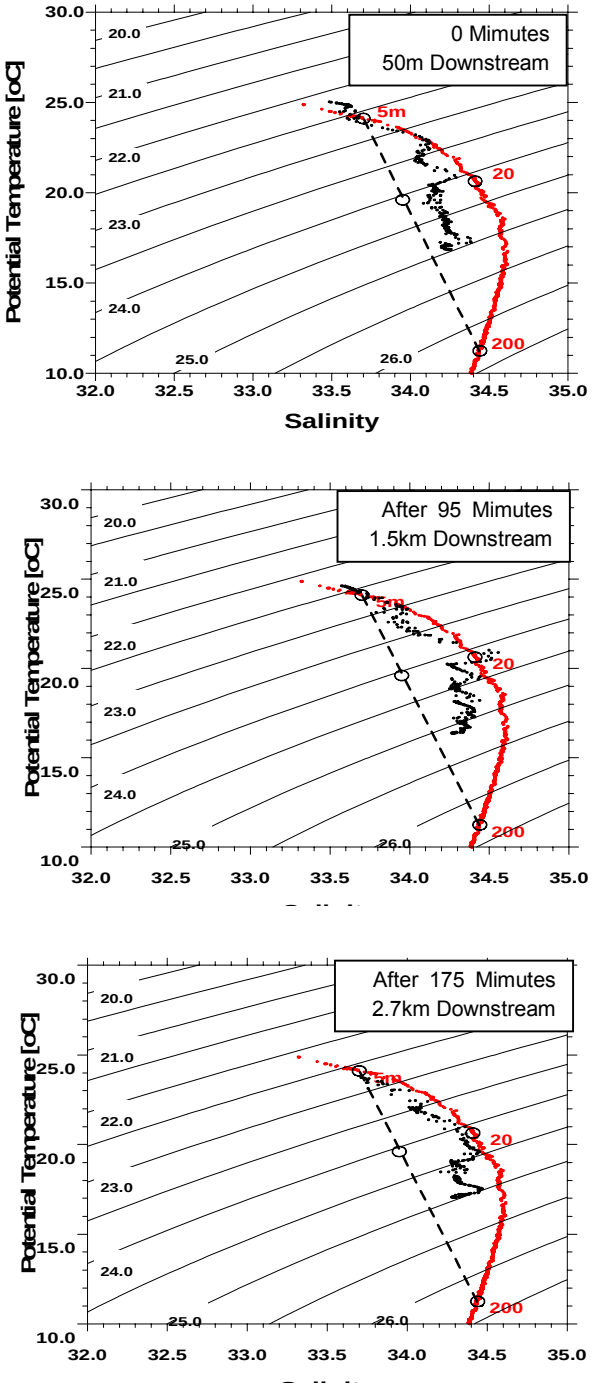

Fig.14 T-S Diagram of the Water mass from TAKUMI

IV. CONCLUSIONS

A new concept ocean floating structure of Ocean Nutrient Enhancer (ONE for short) is proposed as the means to create fishing ground in the open ocean using Deep Ocean Water (DOW).

The main technology features stated as follows were studied through the tank tests, the simulations and the basic designing.

1) The technology to let the DOW's nutrient salt stay in a euphotic zone as a density current.
2) Finding suitable area for the experiment and investigation of the rotational flow characteristics and water quality in Sagami Bay
3) Design of the submerged floating structure, the riser, the mooring system which withstand against very rough sea condition in the open ocean.
4) Upending technology for the riser pipe as reasonable setting up operation.

As a result of these studies, the realization of the TAKUMI experiment is successfully continuing in Sagami Bay.

Regarding the investigation of the fertilization effect, the measurements of water mass quality from TAKUMI agrees that high density DOW is remaining as a density current in the layer of euphotic layer of 20 to 30m depth. Further investigation and research should be needed to know an quantitative effect of TAKUMI.

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