

A Proposal for the Refreshment of Coastal Zone Utilizing wave Energy

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Wave energy is a renewable and clean energy resource, its total amount is infinite in spite of the low density of energy, and it can be utilized anywhere in the ocean coastal zone. It is becoming more attractive as the environmental problems of pollution of seawater and the sea bed become more and more serious year by year.

The authors propose a system in which wave energy promises more effective and more suitable utilization of coastal zones. Wave energy is absorbed by the floating offshore wave power device "the Mighty Whale" through which the wave energy is converted to the energy of compressed air. Compressed air is transported into an enclosed bay with clean seawater, which can refresh the seawater and sea bed.

According to the discussion of the system, authors have tried to roughly estimate construction cost. In this estimate, the length of the Mighty Whale is assumed as 100m, and there are 9 air compressors of to 60 kW rated power on it. This system has the capability to improve an area of 1km square in the ocean by aeration and clean seawater from offshore. The authors estimate that the cost of this system will be about 1.8 billion Japanese Yen.

Furthermore, the Mighty Whale has other characteristics. These include effective dissipation of waves, and the possibility for the marine sports and amusement facility a offshore.

Key words : Wave energy, Wave power device, Ocean energy, Ocean purification, Refreshment of sea

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1 INTRODUCTION

The 35th President of the USA, J. F. Kennedy, stated that the ocean is the last frontier for human beings in the universe because of the huge resources at state, such as numerous like forms, mineral resources, ocean energy resources and ocean space. Still now, the situation is not changed. Since people face numerous serious problems for our resources at the moment, we should continue to make efforts for the development of the ocean in spite of many difficulties.

However, when we pursue a program of ocean development, we have to consider and pay attention to the ocean and global environmental problems. It is a matter of course to prevent or reduce pollution in sea water, in mud and sand seabeds and even in the air. Furthermore, we need to be careful on the ecosystem in the ocean and the view of the ocean also. Consequently, if we can discover problems in the early stages of the project for ocean development, we should stop and change our course.

For instance, in order to refresh the coastal zone, the current methods utilize "aeration," "exchange of sea water," or "dredging work." However, such methods require energy, and if such energy is supplied by fuel, coal or nuclear power station, these power station may cause "new" pollution for global environment. The oceans must be kept clear and must not generate any pollution. Consequently, energy for the refreshment of the ocean environment must be supplied from an ocean natural energy power station.

To date, authors continue to develop a wave power device, and are carrying out research on the system of this device combined with a system for refreshment of the coastal zone environment. Fortunately, authors have succeed-

ed in developing a unique and high performance floating wave power device, "the Mighty Whale." In this paper, the general concept and its possibility for practical use of the total system using "the Mighty Whale" [1] are discussed, as well as the performance for refreshment and a rough estimation of the cost for construction.

2 UTILIZATION OF WAVE ENERGY

2.1 Characteristics of Wave Energy

When we stand at any seashore, we can see waves which means that we have a possibility for utilization of wave energy at any seashore. However, we need to consider the quantity and quality of wave energy and the cost for its utilization. In spite of the advantage of wave power such as clean and infinite resources, it has been pointed out that the power changes in every moment, and the total amount of power extracted by one power unit is not very much in comparison with the fuel or nuclear power station.

As authors described in the introduction, a wave power plant does not cause any pollution and it is the most suitable power plant for supply of energy in the ocean through the long term. If we can discover and succeed in developing the way to store this energy cheaply and easily in the ocean, the problem which is the last "hurdle" for the practical use will be solved.

The wave power at seashores around Japan is shown in Fig.1 [2], although the average value of wave power fluctuates seasonally, the annual average power per unit length of shoreline around Japan is about 6 kW/m, and it is about 7 kW/m at the coast of the Pacific Ocean. At the coast of the Japan Sea in winter, wave power is more than 20 kW/m. The wave power becomes larger at the offing of ocean. Since the total length of shoreline of Japan is about 30,

000 km, we can select the optimal location for the wave power utilization.

2.2 Conversion of wave power to Compressed Air Power

Recently, the large-Scale energy storage method "the Compressed Air Energy Storage" attracts attention. This is the system to store compressed air in an underground air tank for the purpose of adjustment to the optimal energy supply for a nuclear power station. The compressed air is generated at night using energy from the grid, and it generates the electric power by a gas turbine generator in day time for supplying the energy to the grid.

Kadoyu and others paid attention to this system for the application in the ocean [3], because the ocean has huge space and water pressure in spite of severe circumstances such as waves,

current, tide, wind, salinity, bio-fouling and others. Fortunately, after general research on this system in the ocean, they reach the conclusion of possibility and several merits of this system.

By the way, if we can store compressed air in the ocean, we can utilize it not only for the generation of electric power but also for the refreshment of the coastal zone and "aquaculture." It is necessary to increase the dissolved oxygen in sea water or to exchange sea water by the transportation of sea water from the offing for the refreshment.

Regarding this system, sea water is transported with compressed air as a mixed fluid of liquid and air just the same as the "air lift" method which is proposed as the technology for the mining of manganese nodules from the sea

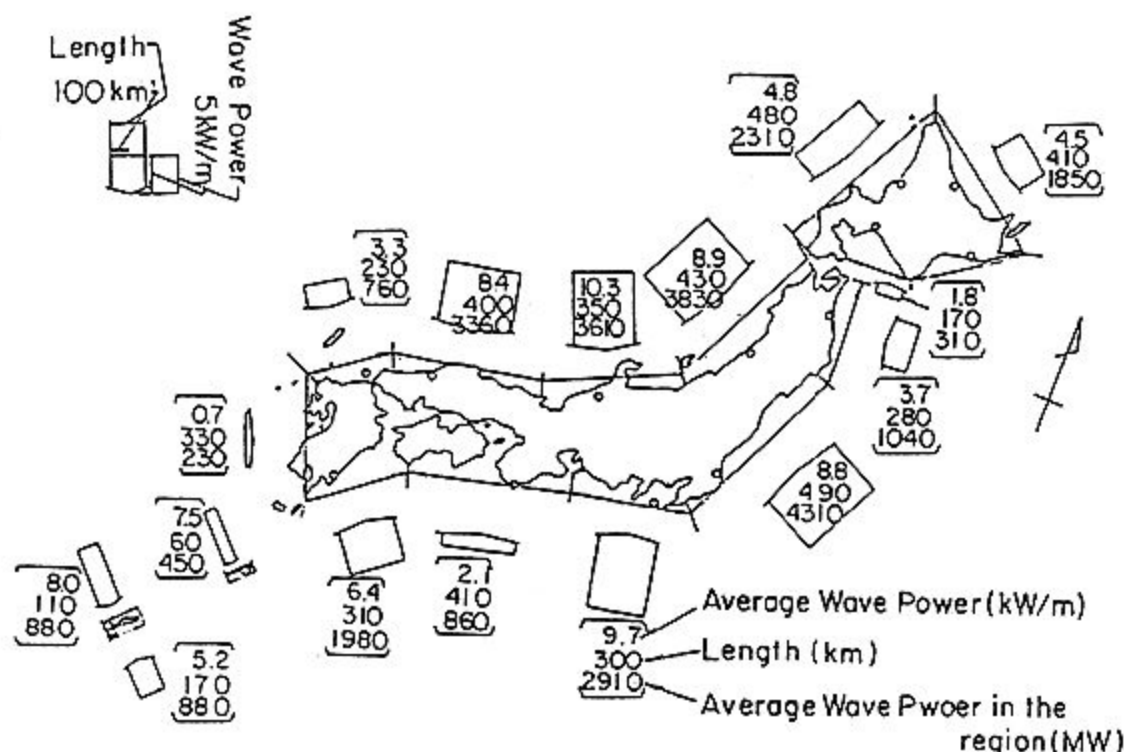


Fig.1 Wave power distribution around Japan

bottom. As for the air transported to near shoreline, it is discharged at the sea bottom for the generation of air bubbles to increase oxygen in sea water, that is, "aeration."

The compressed air is generated by the compressor coupled to the air turbine, which is installed on the wave power device and rotates by the air flow generated by the air chamber of the Oscillating Water Column (OWC) type wave power device, as shown in Fig.2. The optimal matching between the compressor and the air turbine is one of the themes of the research and development on this system. In this report, detail on it are not discussed, however authors guess that the ordinary compressor and air turbines may be available.

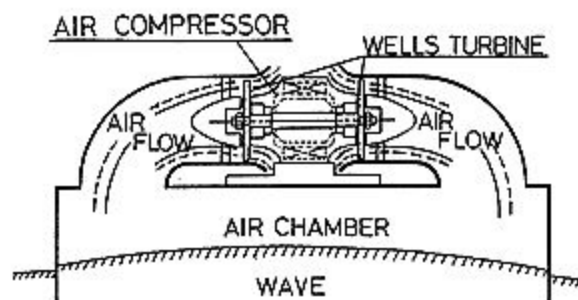


Fig.2 A scheme of wave power conversion system of oscillating water Column type wave power device

2.3 Multi-Purpose Utilization of the Wave Power Device

Since the wave power device can absorb wave energy, it means that the wave power device can dissipate the wave and create the calm sea area behind the device also. However, the performance for wave dissipation of the floating wave power device, such as "the Mighty Whale" shown in Fig.3, is not so good in comparison with the fixed type device, especially in waves of long period such as storm waves.

From the point of view of the effect on coastal environment, such a shortcoming turns into a merit. Naturally, big waves change the sea water in an enclosed sea. However, a man-made offshore structure to protect the waves is used to prevent the change of the sea water, and it causes some pollution problems. Of course, it is very important to keep our lives safe. Authors guess that we will need to consider not only safety but also amenity at the seashore in the very near future.

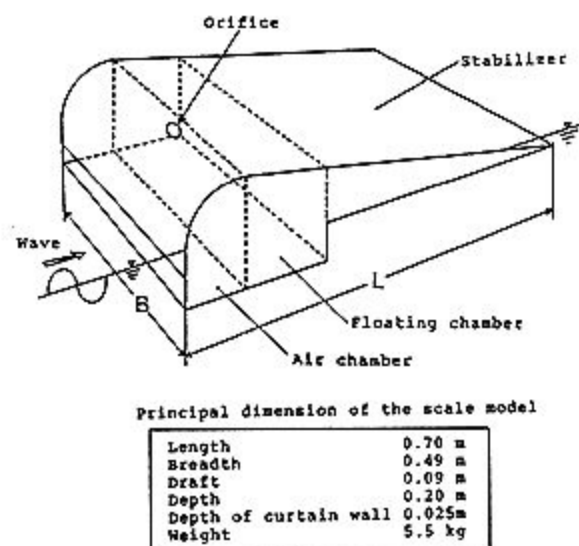


Fig.3 Scheme of the Mighty Whale

Consequently, the floating wave power device such as the Mighty Whale has possibility to be utilized as a floating break water. And, it creates the calm sea area behind the device where "aqua-culture" or many marine sports are available. It means that such a device can create conventional space in the ocean near the sea shore.

3 THE SYSTEM FOR REFRESHMENT OF THE COASTAL ZONE

3.1 Structure of the Mighty Whale

The scheme of the shapes of the Mighty Whale

is shown in Fig.3. It was designed following results of experiments which were obtained by several tests of KAIMEI, which was a proto type floating OWC wave power device tested in 1978, 1988 and 1985 at the offing of Japan Sea [4], the shore fixed type wave power generating system which is tested in 1983 [5] near the test site of KAIMEI. This device is considered from three parts; Air chambers, a floating chamber, and a stabilizer slope. Wave energy is converted to air power by OWC of the air chamber, and drive the air turbine. Presently, the Wells turbine is the most promising because its mechanism is not complicated. The stabilizer slope fulfils function for reduction of pitching motion in waves, and for marine leisure, because this slope is similar to a natural beach and we can swim in and enjoy it.

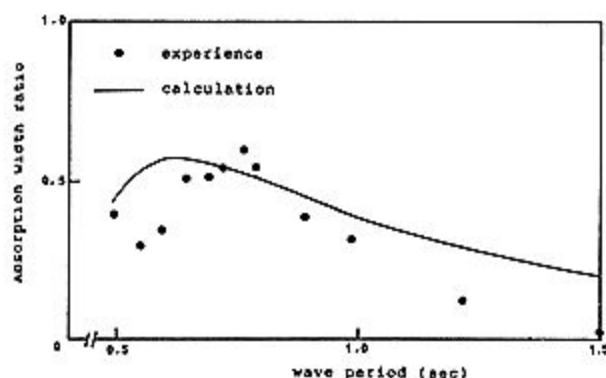


Fig.4 Performance of wave energy absorption in regular waves by the Mighty Whale

3.2 Performances of the Mighty Whale

Fig.4 shows the efficiency of conversion of wave power into air power (wave power absorption) versus wave length (λ) divided by length (L) of the device [6]. The data in this figure are obtained by the two dimensional scale model test of 1/100 in regular waves. The maximum efficiency of wave power absorption is about 60% and the width of band of high efficiency is wider than that of the former type

of the floating wave power device. These results means the Mighty Whale has excellent performance in wave power absorption.

Fig.5 shows the performance of dissipation of incident wave, that is the ratio of transmitted wave height divided by the incident wave height versus λ/L . Since the scale of this model is 1/100, it was 80% within the range of normal sea state at the coast of Japan.

The above results indicate the performance of the Mighty Whale in wave power absorption and dissipation of incident waves are excellent, and better than former types of devices. The reasons for this performance are supposed that the motion of pitching responding to waves is very small due to the stabilizer slope, and coupling motion between the air chamber and OWC.

By the way, the steady drifting force in the waves is very small also, and the minus values were measured sometimes as shown in Fig.6. In this figure, the vertical axis is the drifting force, ρ is density of sea water, g is gravitational acceleration, B is the breadth of device and H_w is wave height. This figure means the Mighty Whale will be able to go ahead against incident waves sometimes, so that the mooring force is very small in general. Consequently, it was made clear that it will not be difficult to moor the Mighty Whale in waves. Authors guess that this propulsion effect in waves is one of the ways to utilize the wave energy.

3.3 Cost of the Mighty Whale

Authors tried to roughly estimate the cost for construction and installation of the Mighty Whale [7]. The total weight of structure of the Mighty Whale of 100m in length will be about 5,700 tons. If we can assume that more than 100 units of the Mighty Whale will be constructed in the future, rough estimation for the construc-

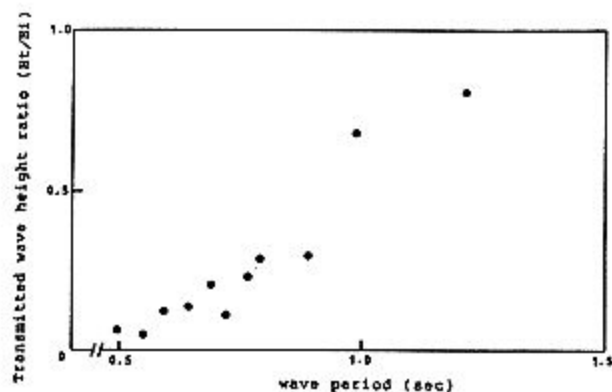


Fig.5 Performance of wave height dissipation by the Mighty Whale

tion of such structure may be about 175,000 yen per one ton of steel weight. So, the cost of this Mighty Whale will be about 1 billion yen per unit.

The cost of the turbine and compressor per chamber will be about 30 million yen. So, the total cost for such equipment for one unit of the Mighty Whale (9 air chambers), including control equipment and other, will be 300 million yen.

The cost for installation including the cost for towing and the mooring chain and anchors may be about 400 million yen per unit. Of course, the cost for such work depends on the site and conditions for installation. So, authors estimated this cost from the experience of KAIMEI test and modified the results for the Mighty Whale.

3.4 The Compressed Air System

The compressed air which is generated on the Mighty Whale is transported to the air tank which is installed near the Mighty Whale on the sea bed and balanced with water pressure. Its scheme is shown in Fig.7. It has a valve to control the situation of charge or discharge of

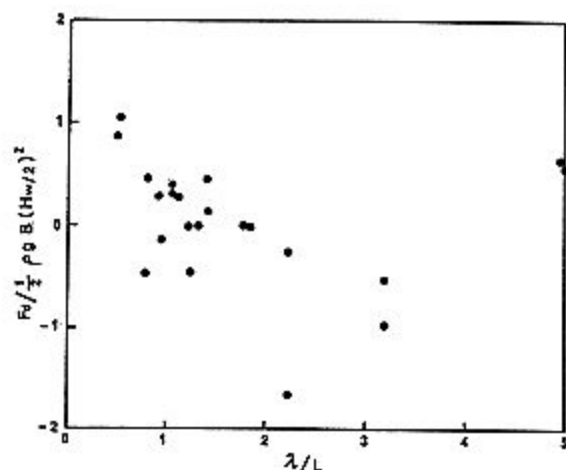


Fig.6 Characteristics of mooring force of the Mighty Whale

compressed air and sea water, which is charged to adjust the pressure in the air tank. The sea water charged in the tank is transported to near the shoreline as same as the compressed air when the air is being charged. The tank has a function for a man-made gathering-place for fish because of the complicated structure around the air tank.

The designed dimension of the air tank is 1.5m in diameter, 20m in length, 60mm in thickness of the wall. The volume in the tank is about $20m^3$, and authors assume it will be installed at the point of 30m in water depth and 1.5km from the shoreline. Furthermore, the subsea pipe to transport the compressed air and sea water was designed as 50mm in diameter.

The cost for construction of the air tank will be about 30 million yen, and 10 million yen for the subsea pipe line. And the cost for installation of the air tank and the pipe lines will be 60 million yen. Consequently, the total cost for the compressed air system will be about 1.8 billion yen.

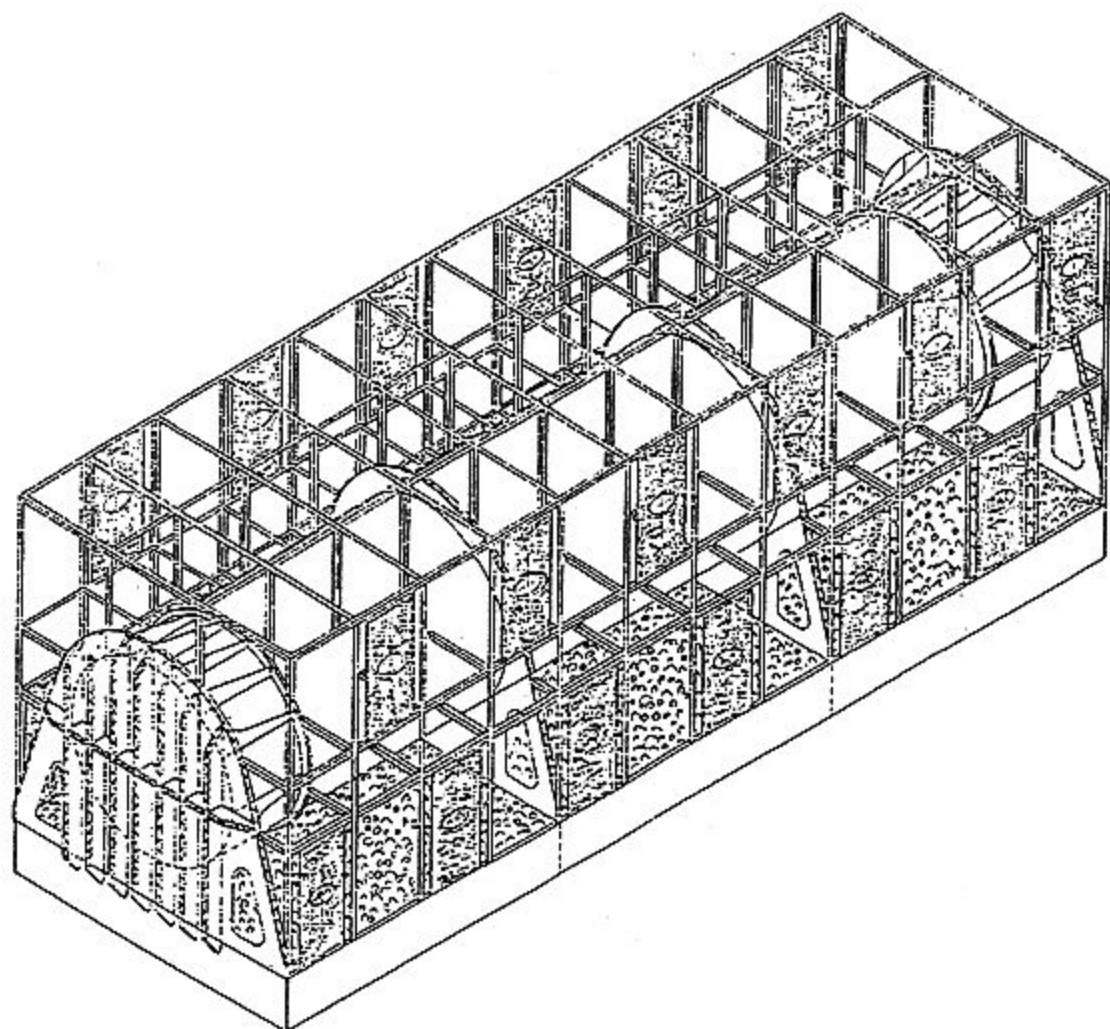


Fig.7 A compressed air tank included into a man-made gathering-place for fish

4 ABILITY FOR REFRESHMENT OF COASTAL ZONE

Authors predicted the air power converted by the Mighty Whale from wave power, the volume of the compressed air, and effective area for aeration near the seashore by one unit of this system.

When we assume that the Mighty Whale will be installed at the site of 2m in the significant wave height and 8 seconds in the significant wave period, the total input wave power for one unit of the Mighty Whale is about 1,400 kW. Since the average efficiency in regular waves of

the wave power absorption is about 50%, and the average efficiency of the turbine is about 40%, the input power for 9 units of air chamber to the air compressors is about 280 kW. Consequently, the rated power of the air compressor is about 30 kW.

When the air must be compressed up to 4 kg/cm² because the air chamber will be installed on the sea bottom of 30m in water depth, the air compressor of 30kW in rated power can generate the compressed air of about 1400Nm³/day. Since the Mighty Whale is designed in this paper has 9 units of the air chamber, air turbine

and compressor, the total volume of the compressed air for the Mighty Whale in a day will be about $13,000\text{Nm}^3/\text{day}$, that is about $0.15\text{Nm}^3/\text{sec}$.

By the way, when this compressed air will be utilized for aeration at the point 8m in water depth, it is estimated that the discharge of air of $0.01\text{Nm}^3/\text{sec}$ can make some effects for the increase of dissolved oxygen in sea water for the area in the coastal zone with a radius of about 50m.

Furthermore, when we consider the horizontal diffusion of air bubbles, and the effect of breaking of the layer of sea water by vertical current caused by the movement of bubbles from the sea bottom to the surface, the effective area by the aeration may widen about double in radius.

Consequently, we can design the distance between each air pipe line on the sea bed for the aeration at about 250m, and this system has 16 nozzles for blow out of the air bubbles. It means authors estimate this system can supply air for

the dissolvment of oxygen to the sea of about 1 km around.

5 CONCLUSION

In this paper, the following conclusions were obtained.

- (1)The possibility and the performance of a system for the refreshment of sea water in coastal zone utilizing wave power is discussed and authors reach a possible positive solution.
- (2)It was estimated that the system using the Mighty Whale of 100m in length as a floating OWC type wave power device can make refreshment for the sea water of the area of about 1 km around by aeration.
- (3)The cost for construction and installation of this system was estimated roughly. It was about 1.8 billion yen for the total system which has a function concluded in (2).
- (4)Authors believe that with this new way to develop and utilize coastal space, energy can be proposed to keep nature in the coastal zone.

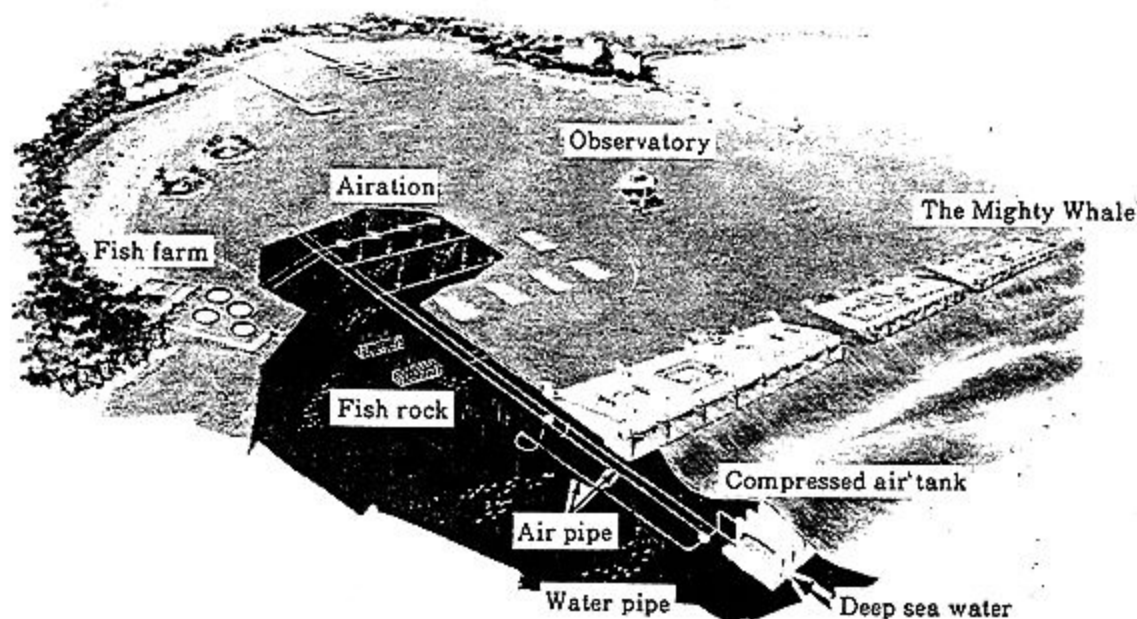


Fig.8 A scheme of the future plan for the utilization of the Mighty Whale for the coastal development

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波エネルギーを利用した沿岸海域環境 改良技術に関する一提案

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これまで沿岸の波浪は、海洋を利用する場合、最も障害となる自然条件ととらえ、その抑制に主眼を置いてきた。しかし、近年の波浪エネルギー利用技術の進展により、波浪を利用可能なエネルギーに変換するとともに静穏海域を創出し、積極的に利用する研究が実施されている。

沖合浮体式波力利用装置（マイティーホエール）は、この目的に適合した装置で波エネルギーを空気室を用いて効率よく吸収し、利用形態に合わせて電力・圧縮空気などに変換し、これを用いて沿岸海域の浄化を行う。

基礎研究の結果に基づき、全体形状、空気室形状を決定し実機の設計を行った。構造部材は鋼構造、コンクリート構造、ハイブリット構造を検討したが、ここでは鋼構造について示し、その概略の建造コストを求めた。

また、マイティーホエールが吸収できる波エネルギーをスケールモデルを用いた性能試験結果から予測し、そのエネルギーを利用して作り出せる圧縮空気量の推定を行った。そして更に、この圧縮空気により水深10mの沿岸海域においてエアレーションを行った時の有効面積も推測した。

その結果、長さ100mのマイティーホエールを用いたシステムの建造費が約18億円であり、それにより1km四方の沿岸海域を浄化することができることを推測することが出来た。

キーワード：波エネルギー、波力装置、海洋エネルギー、海洋浄化、海域環境
改良

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