# A Preliminary Study of a Submersible Facility for Abalone Spats

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**The abalone shell (*Haliotis*) is one of the most important resources for the coastal fisheries and it is popular as an aquacultural species. Proper cultivating grounds for mid-term nursery of abalone spats are required before releasing them. It is difficult for us to find good enough aquacultural grounds to rear abalone spats to 20~30mm of shell length. Therefore, we need to study a practical and effective new type of aquacultural device for the nursing of abalone spats by using open sea areas. We can find this kind of studies from "Marine aya No. 1" of Japan.**

**Though they focused on the easy operation, safe working and low operating cost, it involves so much initial cost that it is difficult for us to justify such expenditure. However, with a modified small buoy system, this submersible facility needs only a horizontal frame to fulfill its essential function and the vertical part can be removed. The working boat equipped with a pump can operate this facility to keep it submerged or floated. This paper deals with the possibility of this submersible fishery facility for the mid term nursing of abalone spats in the open sea. A small version of this system to ensure low initial cost is suggested and wave and current forces were calculated for the estimation of the weight of the mooring anchor.**

**Key words** : submersible facility, abalone spats, aquaculture, wave & mooring forces

## Introduction

The sea water quality of the East Sea of Korea is quite good for aquaculture but the slope of the coastal region is steep and the depth is too great. If we develop new devices to utilize the open sea as aquaculture grounds, it would be very beneficial for fishermen. The Ministry of Fisheries and the National Fisheries Research and Development Agency are interested in developing advanced technology in the field of coastal fishing (Yoon, 1994).

This paper deals with a preliminary study of this submersible aquaculture facility for the mid-term nursing of abalone (*Haliotis*) spats to 20~30mm shell length before releasing to the fishing co-operative grounds.

In Korea, this technique of artificial rearing of abalone spats was established in the 1970s and it is a popular form of aquaculture. The size of abalone supplied from the hatchery to fishermen is around 10~20 mm in shell length. The survival rate of adults is as low as 10%. But if we culture them to 30~40mm of shell length for nearly 7 months and then release them, their survival rate goes up to 30~60% (Kim, 1991).

Therefore we need to develop a new device for the mid-term rearing of abalone spats.

## The Concept of Submersible Fishery Facility

In Korea, many species like oyster, sea squirt and scallop have been raised by suspended devices. These methods can make use of sea areas 3 dimensionally. Traditionally the retail value of abalone is high, it is a popular aquacultural species for the co-operative fishing industry. Unfortunately nowadays the quality of sea water is degraded, it is difficult to find proper places for the mid term rearing of abalone spats. With the development of floating facilities for aquaculture, we can make use of the open sea as aquacultural grounds. This kind of study should be supported by government authorities because of the technical and high economic risk of such research for individual private companies.

We can find such an example in Japan. They made "Marine aya No. 1" in 1990 and tested its suitability for abalone aquaculture (Okamoto et al., 1992). They reported high success rates for abalone and black rock fish culture. Though they say they developed that system focusing on ease of operation, safety of operation and low operating cost, they might have spent a great initial capital expenditure. It is difficult for small commercial enterprises to invest. If we use a modified small buoy system, this submersible facility can be managed with only a horizontal frame fulfilling the essential function and the vertical part can be removed as in Fig. 1.

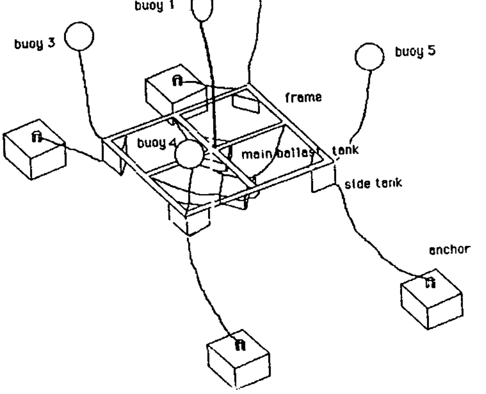


**Fig. 1. Configuration of the submersible facility for mid-term nursery of abalone spats.**

The working boat with a pump can operate this facility submerged and floated. The length of the center buoy for ballast should be long enough for the working boat not to be over the floating facility.

## Selection of Design Condition

Design specifications should normally be decided from the characteristics of the installation place. But this study is only a preliminary study to find out approximate environmental forces and the technical feasibility of such a design. So design specifications were made conservatively for possible usage in more open coastal regions.

The frame size was selected as 10 m(L)×10 m(B) ×1 m(D) for lower initial cost and the depth was 30 m where scuba activity was possible for the installation of the frame and anchors. An area was chosen with an average wave height of 3 m - the norm for Korean coastal waters. The average current of the area selected was 1 kt, also typical of the more open coastal aquaculture waters. This environmental conditions were equivalent to sea state 5 and the low end of the Beaufort scale 6.

The state of the sea surface was "incipient large waves"; the white foam crests were more extensive everywhere and the wind was "strong breeze."

These environmental conditions were much less than those of typhoon. Pre-typhoon swells come one or two days prior to the typhoon's arrival.

At that time, providing with plenty quantity of fodder like sea weed and keeping the frame submerged for five or six days, we can minimize the disaster of typhoon.

This paper deals with preliminary calculation of the submersible aquaculture facility for the mid-term

**Table 1. Design specifications of the modified submersible aquaculture facility**

| | Design Specifications | Remarks |
|---|---|---|
| Dimension | 10×10×1m | low initial cost |
| Depth | 30m | scuba activity |
| Average wave height | 3m | near sea |
| Wave period | 8.5sec | sea state 5 |
| Current | 1.0kt | wider range |

nursery of abalone spats. For the estimation of the weight of mooring anchor, wave and current forces should be calculated in advance.

## Wave and Current Forces

To study the wave forces for short wave length compared with the length of submersible facility, we considered 2 rectangular coordinated systems, one (xyz axes) is for a fixed frame and the other (x'y'z' axes) was for incidental waves with arbitrary angles ($\mu$) as in Fig. 2. Both z and z' were on the same axis that was protruding upward. These two axes were related to each other as follows:

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{bmatrix} \cos\mu & \sin\mu \\ -\sin\mu & \cos\mu \end{bmatrix} \begin{pmatrix} x \\ y \end{pmatrix} \qquad (1)$$

The oscillating wave exciting force was composed as

$$\vec{F} = \vec{F_1} + \vec{F_{21}} + \vec{F_{22}} \qquad (2)$$

in which $\vec{F_1}$ was an undisturbed pressure force, the so called Froude-Krilov force, $\vec{F_{21}}$ was the added force and $\vec{F_{22}}$ was the viscous force.

For the Froude-Krilov force, we could integrate an arbitrary incidental wave along the surfaces of the tanks.

$$\vec{F_1} = -\iint P\vec{n}\, ds = -\int_{-T_s}^{0} \oint_{barge} f(z')\sin(\omega t - kx')\vec{n}\, dC\, dz' \qquad (3)$$

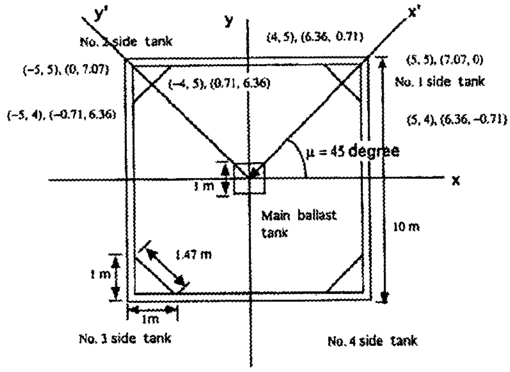


**Fig. 2. Upper view of the submersible aquaculture faclity.**

where dC was an infinitesimal quantity of contours of the tanks and $\vec{n}$ was the outward normal unit vector along the contour. $T_s$ is draft and $f(z')$ indicates function of z'.

$\vec{F_{21}}$ could be calculated by means of the so-called small body theory (Hooft, 1982; Yoon et al., 1994). A precise calculating method for wave force such as source distribution method has been established already in marine hydrodynamics. But it is too complicate to use for the early stage of design. Small body theory is a simplified calculating method for the wave force for the small range of wave length compared with the length of a floating body where inertia force is dominant.

To find out the maximum wave force for long wave compared with the length of a floating fishery facility, Morison's equation is more convenient than small body theory because of the limited data for the estimation of added mass coefficients and viscous coefficients of specific shapes.

$$dF = \frac{1}{2} C_d \rho D\, U|U|\, ds + C_m \rho A \dot{U}\, ds \qquad (4)$$

where $C_d$ : drag coefficient

$C_m$ : mass inertia coefficient

U : undisturbed finite depth water particle velocity. If a steady current is present, it should be added vectorially to it.

$\dot{U}$ : undisturbed finite depth water particle acceleration

$\rho$ : density of water

D : diameter of cylinder

A : projected area of cylinder

The total wave force and current force ($F_t$) for the tanks was composed of drag force ($F_D$) and inertia force ($F_I$). For 30 m water depth, the wave length whose period is 8.5 sec is 102 m. The maximum water particle velocity is 1.58 m/s. With the current of 1 kt, U is 2.08 m/s. The coefficient of $C_m$ is estimated for 1.89 and $C_d$ is 1.6 from the exsisting data (Hallam et al., 1977; Matsubara et al., 1994).

$$F_t = F_D + F_I$$
$$= 25{,}814 \cos^2(\omega t - kx) + 6849 \sin(\omega t - kx) \ \text{(N)}$$

The buoy was small compared with wave length and took only drag force. But the drag coefficient of the buoy varied according to Reynolds No. The coefficient of sphere was calculated according to the Chow's description (Chow, 1979). The Reynolds No. of the buoy with the diameter of 50 cm was

$$2.02 \times 0.5/(1.519 \times 10^{-6} \text{m}^2/\text{s}) = 1.33 \times 10^7$$

This was in the high range of the Reynolds No. and the drag coefficient of buoy was 0.18. The wave force was composed mainly of a dominant drag force.

$$F_D = \pm 369.5 \cos^2(\omega t - kx) \ \text{(N)}$$

With nearly the same process, the drag force for the 4 mooring chains (dia. 9 cm) is assumed to be 7716 N. Thus the total force was composed of the above forces as in Fig. 3.

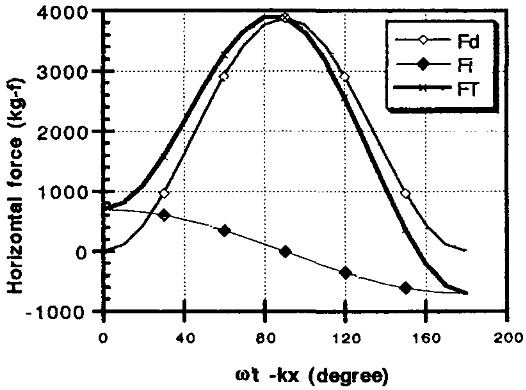


**Fig. 3. Total wave and current force for the submersible facility.**

$$F_T = \pm 33{,}899 \cos^2(\omega t - kx) + 6849 \sin(\omega t - kx) \ \text{(N)}$$

Thus the horizontal force for one mooring line at the fairleader was 3,452 kg-f.

A heavy chain was chosen to reduce the weight of the concrete anchor as follows. The weight of stud chain of its diameter 76.2 cm was about 4 ton for the length of 15 fathom (27.4 m) (Mayers et al., 1969; Okamoto et al., 1992).

$$\phi 76.2 \text{ cm chain} \times 27.4 \text{ m} + \phi 25.4 \text{ cm chain} \times 50 \text{ m}$$

The diameter of buoy can be determined for buoyance force and easy accessibility. If the fishery facility has enough buoyance, the smaller diameter of buoy would take less dynamic forces.

## Calculation of Mooring Force

For the calculation of the mooring force of the catenary moored spread system, basic catenary mooring line patterns were designed as in Fig. 4.

The formulae of the relationships between the

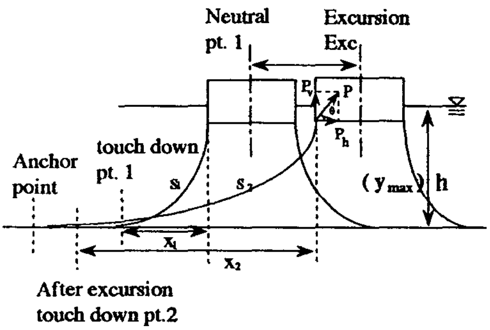


**Fig. 4. Configuration of catenary mooring system.**

mooring line length and the tension of the catenary mooring system were as follows:

$$(y-\frac{P_h}{w})^2=s^2+(\frac{P_h}{w})^2 \quad (5)$$

$$y=(\frac{P_h}{w})[\cosh(wx/P_h)-1] \quad (6)$$

$$s=(\frac{P_h}{w})\sinh(\frac{wx}{P_h}) \quad (7)$$

$$P_v=ws \quad (8)$$

$$\theta=\tan^{-1}(\frac{P_v}{P_h}) \quad (9)$$

where x : horizontal distance of projected mmooring line
y : vertical distance of projected mooring line
$P_h$: horizontal component of tension
w : wire weight per unit length in water
s : uplifted mooring line length
$P_v$: ertical component of tension
$\theta$ : angle between fair lead and catenary line

The neutral point is determined from the initial tension of mooring line. Excursion is the distance from neutral point (Yoon and Chu, 1993).

Line tension and line length were greatly changed according to $\theta$. When $\theta$ was decided first, $P_h$ was rearranged as the following quadratic equation.

$$(\tan\theta w)^2 P_h+2y/w\, P_h+y^2=0$$

Calculation started from the value of $\theta$ and all other values were calculated for the adequate interval of $\theta$ for one mooring line. In deep water where the mooring line is much longer than extension, only vector sum of extension was enough in engineering sense, but in shallow water the projected length of mooring line should be treated with extension length.

## Selection of Anchor

The selection of the type of anchor depended on the maximum mooring force, bottom conditions, and the various available methods for placing the anchor. The four basic anchor types normally used with fishing facilities for shallow sea were deadweight anchors, embedment anchors, screw anchors and pile anchors.

The most commonly used anchor is the concrete block deadweight anchor which is usually cast at the site (Berteaux, 1976). The design anchor weight ($w_t$) of these anchors can be determined by the following relationship based on a static analysis.

$$w_t=\frac{F_t\, F_s}{\mu(1-\frac{W_w}{W_c})} \quad (7)$$

where
$\mu$ : the coefficient of static friction
$w_t$ : the total weight of concrete anchor in air
$w_w$ : the unit weight of water (1025 kg-f/m$^3$)
$w_c$ : the unit weight of concrete (2400 kg-f/m$^3$)
$F_t$ : the lateral mooring line load
$F_s$ : the factor of safety (1.5)

If the bottom is assumed to be level firm sand, the coefficient of static friction, $\mu$, is assumed to be 0.4. Thus, using $F_s=1.5$ and $F_t\ F_s=335\times1.5=502.7$ kg-f.

$$w_t = \frac{502.7}{0.4(1-0.416)} = 2{,}152 \text{ kg-f}$$

The volume of concrete anchor was

$$\frac{2{,}152}{2400} \simeq 0.90\text{m}^3$$

Thus the size of the anchor was a cube of its length which was 0.966 m.

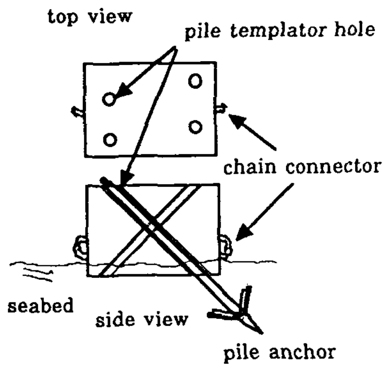


**Fig. 5. Suggested configuration of the revised concrete & pile anchor block for shallow sea.**

If the depth is less than 30 m, scuba activity is possible for pipe templating work. The capacity of resistance of anchor can be enlarged with x shaped, slanted piles as in Fig. 5. Piles stuck well in seabed can be expandable by itself with the action of small waves. It is expected to resist for the large wave force of typhoon. It has been submitted for the patent. The changes of position of the buoy in floated and submerged conditions seemed not so great and were easily calculated with static analysis. The movement of the buoys and frame might exert dynamic forces on the frame and should be examined by using time domain analysis for the next detail design stage.

## Conclusions

A preliminary study was carried out for the approximation of wave and current forces and the selection of anchor weight and intermediate results are reported in this paper. To increase anchor resistance, a revised anchor in shallow seas is proposed. With modified small submersible facilities, the utilization of open sea areas for the rearing of mid-term abalone spats is proposed. This kind of study should be continued for the model and prototype test for the development of aquacultural grounds and for the continued economic health of the fishing industry of Korea.

## Acknowledgements

This research was partly supported by RCOID, NFUP and KRISO and proof reading was done by P. Ackroyd, Professor of NFUP. I would like to express my heartest thanks to the persons concerned.

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Received April 19, 1995
Accepted July 10, 1995

# 부침식 전복치패 중간육성장치 개발을 위한 초기연구

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전복은 연안 양식장의 가장 중요한 자원의 하나이며 인기있는 양식 종류이다. 전복을 공동어장에 방류하기 전에 전복치패를 중간육성할 적당한 중간육성장이 필요하다. 그러나 전복치패가 패각이 20~30 mm 정도로 기를 중간육성장을 찾기가 쉽지 않다. 따라서 넓은 해역을 전복 치패 중간육성장으로 이용하는 보다 실용적이고 효과적인 양식시설의 연구가 필요하다. 우리는 이러한 종류의 예를 일본의 "Marine aya No. 1"에서 찾을 수 있다.

그들의 연구가 조작 용이, 안전 작업 그리고 저렴한 운용비에 초점을 맞추었다고 하더라도, 초기 제작비가 커서 우리가 기대하기는 힘든 수준이다. 그렇지만, Marine aya No. 1의 수직부를 간단한 부이 시스템으로 대치한다면, 수평 후레임만으로 잠수가능한 최소한의 기능을 가질 수 있을 것이다. 펌프를 장착한 간단한 작업선으로 이 시설을 부상 또는 침하시킬 수 있을 것이다.

본 논문은 개방 해역에서 전복 치패의 중간육성을 위한 잠수가능한 양식시설의 개발 가능성을 다루었다. 낮은 초기 제작비를 위해 소형의 부침식 전복치패 중간육성시설과 개량된 앵커를 제안하였고 파력과 조류력, 그리고 계류 앵커의 중량을 계산에 의해 추정하였다.