RECENT ADVANCES IN MARINE SCIENCE AND TECHNOLOGY, 98

NARENDRA K. SAXENA
EDITOR

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ANSAN P.O. BOX 29
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UNIVERSITY OF HAWAII AT MANOA
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Edited by

Narendra Saxena
Professor
School of Ocean and Earth Sciences and Technology
University of Hawaii
Honolulu, Hawaii, U.S.A.

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PREFACE

Recent Advances in Marine Science and Technology, 98 is the fourth refereed publication of a series based upon papers presented at the Eighth Pacific Congress on Marine Science and Technology (PACON 98) held in Seoul, Korea, 15-19 June 1998. A unique process was adopted to bring about this refereed publication: session chairs selected papers based on presentations at PACON 98 and recommended them for possible inclusion in this publication. Each manuscript was reviewed by the session chairman and an external reviewer. Some revised manuscripts were reviewed a second time by the initial reviewer to see that the modifications were duly made. Out of 106 PACON 98 presentations, 91 papers were recommended by session chairmen, 37 manuscripts were submitted, and finally 31 papers were accepted for this publication.

Since papers dealt in areas of ocean sciences, technology, management and policy, we have tried to group related papers to facilitate the reader's use of this publication. I hope that readers will find this volume of 31 papers useful. An index giving the alphabetized list of authors is presented at the end of this volume.

I wish to thank Paula Kuriyama and Richelle Tashima of PACON International, without whose untiring efforts this publication would not have been possible. I would also like to thank Atanu Basu and Rosemarie Geronimo of the Pacific Mapping Program for their assistance in compiling this book. This work was made possible due to the generous support of our sponsors: CEROS, National Defense Center of Excellence for Research in Ocean Sciences; Department of Business, Economic Development and Tourism (DBEDT), State of Hawaii; Korea Ocean Research and Development Institute; Ministry of Maritime Affairs and Fisheries of Korea; Ministry of Science and Technology of Korea; Office of Sustainable Development and Intergovernmental Affairs, NOAA, U.S. Dept. of Commerce; PACON International; The Medical Foundation for the Study of the Environment and the Human Body Charitable Trust; U.S. Geological Survey (USGS); University of California, Sea Grant College Program; University of Hawaii at Manoa; University of Hawaii at Manoa, College of Engineering; and University of Hawaii at Manoa, Sea Grant College Program.

Honolulu
June 4, 1999

Narendra K. Saxena

PROMENADE BREAKWATER WARNING SYSTEM

Tetsuya Hayakawa[1], Kimihiko Endo[1], Katsutoshi Kimura[1] and Michifumi Hayashi[2]

[1]Civil Engineering Research Institute, Hokkaido Development Bureau
Sapporo, Hokkaido, JAPAN
tetsu@ceri.go.jp

[2]Cold Region Port and Harbor Engineering Research Center
Sapporo, Hokkaido, JAPAN

ABSTRACT

This study proposes a new system to appropriately evaluate the level of danger from overtopping waves and to warn people of such danger on promenade breakwaters. The shape of the seaward side of the upright breakwater is modified for this system. Sounds and splashes are generated before wave overtopping occurs. Hydraulic model experiments made conducted to clarify the mechanism of sound and splash generation. The sound pressure level and the splash height were expressed by a formula of wave and structural conditions. The sound generation characteristics were clarified from the numerical simulation. The splash heights calculated from wave conditions tended to agree with field observation values.

INTRODUCTION

In addition to their original function of protecting the harbor from waves, breakwaters are attractive places from which to fish and to enjoy the landscape of the port and sea. Hence, a new type of breakwater, called the promenade breakwater, has been constructed recently in Japan. However, overtopping waves make such breakwaters very dangerous for people. Administrators of breakwaters must fully understand the dangers of such facilities and properly address the safety of people on these structures. This study proposes a new system to appropriately evaluate the level of danger from overtopping waves and to warn people of such danger on promenade breakwaters.

Figure 1 is a conceptual drawing of the warning system to be installed at a promenade breakwater. The shape of the seaward side of the upright breakwater is modified for this system. The system consists of a ditch called the "mouth" and an upright opening called the "nozzle". Sounds at the mouth and splashing at the nozzle are generated when a wave reaches the mouth and breaks against the inside wall. These sounds and splashes make people at each place along a breakwater and its administrator aware of the danger of wave overtopping. Because the mouth is lower than the crown, alerting people before wave overtopping occurs is possible. Furthermore, the height of warning

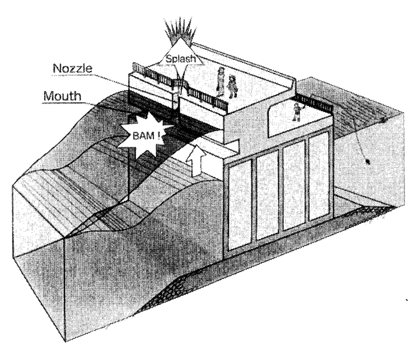

Figure 1. Conceptual Drawing of System

waves can also be adjusted by changing the installation position of the mouth. It is therefore possible to adjust the leeway time before waves actually overtop breakwaters, endangering people on the breakwater.

In this study, hydraulic model experiments, a numerical simulation and field observations were conducted to examine the characteristics of this warning system.

OUTLINE OF EXPERIMENTS

The experiments were conducted in a two-dimensional wave channel(85×1.6×3 m). Figure 2 shows a model breakwater, which has a mouth and nozzle, with installation water depth, h, of 1.23 m. The height from the still water level to the bottom of the mouth, h_{s1}, was 18 or 28 cm, the depth of the mouth, B_s, was 6, 10 or 20 cm, the height of the mouth, h_{s2}, was 10 cm and the width of nozzle, L_n, was 10cm. Regular waves were used for the experiment and the relative water depth, h/L, was between 0.095 and 0.277, while the ratio of the wave height to water depth, H/h, was between 0.163 and 0.366.

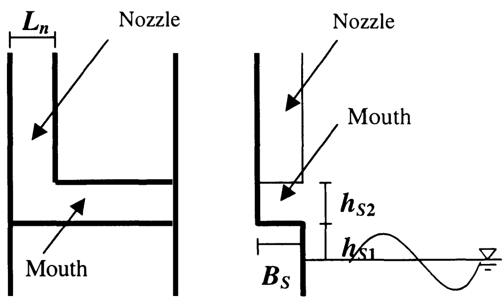

Figure 2 Model of Breakwater

In the experiment, wave motion at the mouth and nozzle were observed using a high-speed video camera (250 frames/s). The sound pressure levels were measured using a noise meter. The splash heights were determined by visual inspection. Two wave gages were also placed in front of the breakwater to measure water levels.

SOUND CHARACTERISTICS AT MOUTH

Wave motion and sound generation mechanism

Figure 3 shows the wave motion around the mouth under the condition of h_{s1} = 18 cm, B_s = 10 cm, H/h = 0.244 and h/L = 0.175. After the water level in front of the breakwater rises and reaches the bottom of the mouth section, the wave surface falls into the mouth.(1~2) The wave surface reaches the top of the mouth section and the air is trapped inside the mouth.(3) The wave front hits the back wall of the mouth.(4) Then, as the water level rises, the water and air become mixed in the

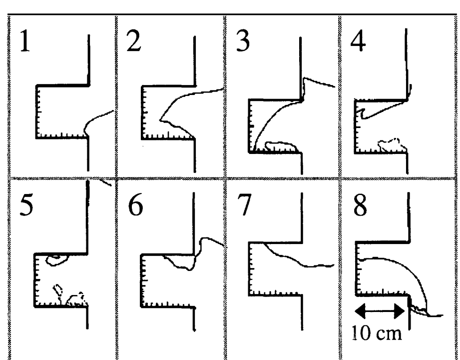

Figure 3 Wave Motion around Mouth

mouth. (5) As the water level falls below the mouth section, the water remaining in the mouth begins to flow out.(6~8)

Figure 4 shows the time series of sound pressure and sound pressure level under the same condition as in Figure 3. The sound pressure is characterized by two large peaks, the first peak has a short reaction time and the second has long peak. Regarding the relation with the wave motion, the first peak occurs when the water level rises and the wave pressure increases in the wave motion 3 and 4. When the water level falls, it increases in motion 6 and 8. These phases in which the sound pressure increases are defined as follows:

Phase Ia: The compressed air is pushed out from the top of the mouth when the water level rises and reaches the top of the mouth

Phase Ib: The wave front hits the back wall of the mouth.

Phase IIa: The air flows into the mouth when the water level falls and reaches the top of the mouth.

Phase IIb: The water level falls below the mouth and the water in the mouth falls out.

Regarding the sound pressure level, there were two large peaks. The first peak, SPL1, was in Phases□a and□b when the water level rose. After the wave pressure increased sharply and peaked, there was also a large decrease. The second peak, SPL2, was in Phases □a and □b when the water level fell and the rise and decrease was relatively gentle compared to SPL1.

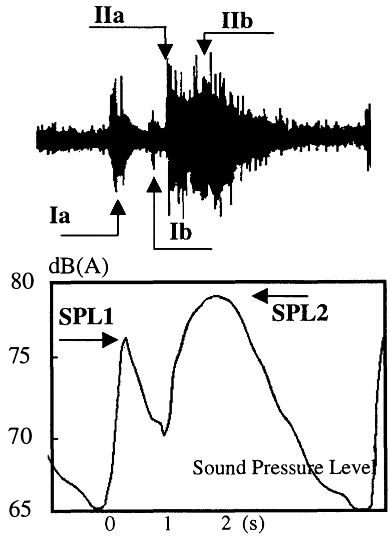

Figure 4 Sound Pressure Characteristic

Characteristics of sound pressure level

Figure 5 shows the first peak of sound pressure level, SPL1, when the water level rose. The X-axis represents the vertical velocity of the wave surface profile at the mouth bottom, V_{sf}, which

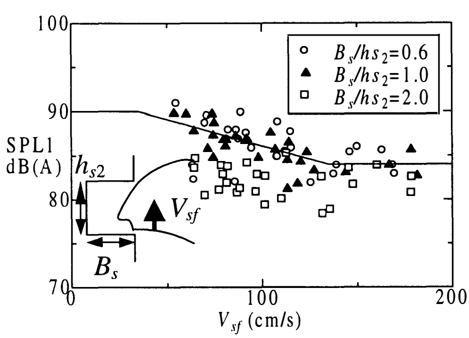

Figure 5 SPL1 and V_{sf}

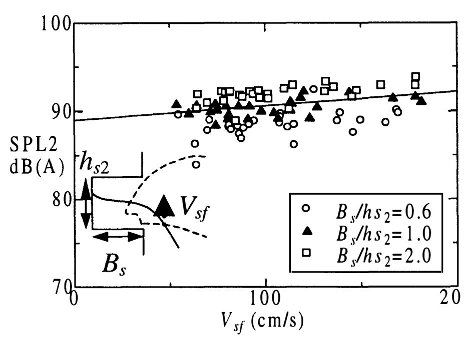

Figure 6 SPL2 and V_{sf}

was measured by wave gages. The main parameters of SPL1 are V_{sf} and B_s/h_{s2} and were 80 to 90 dB(A) depending on the condition. SPL1 decreased slightly when V_{sf} increased. After V_{sf} increased to about 130 cm/s, SPL1 tended to become constant. When B_s/h_{s2} increased, SPL1 tended to decrease. Such differences in SPL1 due to V_{sf} and B_s/h_{s2} can be explained by the sound generation mechanism. When V_{sf} increased, Phase Ia, in which the compressed air is pushed out from the top of the mouth occurred before Phase Ib, in which the wave front hits the back wall of the mouth. The sound pressure level was thought to be dominant in PhaseIa and constantly remained within the range of 80 to 85 dB(A). As the mouth section was deep (B_s/h_{s2} = 2.0), the sound pressure level was dominant in Phase Ia, even though V_{sf} was smaller and SPL1 was stable for the same reason, because the wave front did not hit the back wall. When B_s/h_{s2} = 1.0, SPL1 can be formulated as a function of V_{sf}.

$$SPL1(dB(A)) = \begin{cases} 90.0 & : V_{sf} < 35cm/s \\ 92.1 - 0.06V_{sf} & : 35 \le V_{sf} < 135cm/s \\ 84.0 & : V_{sf} \ge 135cm/s \end{cases} \quad (1)$$

Figure 6 shows the second peak of sound pressure level, SPL2 when the water level fell. SPL2 was dependent on V_{sf} and B_s/h_{s2} as in SPL1. When V_{sf} or B_s/h_{s2} was larger, SPL2 tended to slightly increase and was 85 to 95 dB(A). The reason for its dependence on V_{sf} was thought to be the increase in falling distance from the mouth due to the larger V_{sf} that caused the increase in Phase Ⅰb. Furthermore, when B_s/h_{s2} was larger, the capacity of the mouth increased and the larger volume of falling water caused the increase of sound pressure, even when the falling distance was equivalent. When B_s/h_{s2} = 1.0, SPL2 can be formulated as a function of V_{sf}.

$$SPL2(dB(A)) = 89.0 + 0.016V_{sf} \quad (2)$$

Modeling of generated sound

Figure 7 shows a model of the sound pressure level. The condition of B_s/h_{s2} = 1.0 is considered here. When the water level reached the middle of the mouth, the sound pressure level was SPL1 calculated by Equation (1) and attenuated at the rate of 25 dB(A)/s. The rate of attenuation was found from the values obtained in the experiment. Assuming that sound pressure level started to increase when the water level fell to the bottom of the mouth, the duration of sound was represented as t_{p2} and the maximum sound pressure level was represented as SPL2 calculated by Equation (2). Here, t_{p2} was modeled assuming that the outflow velocity from the mouth at the water level d within the mouth section was $(2gd)^{0.5}$. d_0 represents the level of water remaining in the mouth.

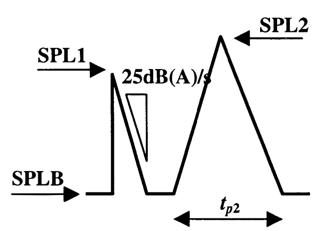

Figure 7 Model of Sound

$$t_{p2} = \frac{2B_s}{\sqrt{2g}}\left(\frac{1}{\sqrt{d_0}} - \frac{1}{\sqrt{h_{s2}}}\right) \quad (3)$$

SPLB in the figure represents the sound pressure level of background noise around the breakwater. As a result of a field experiment, SPLB was determined at 56.5 dB(A) using the average sound pressure level. (The maximum sound pressure level, $SPLB_{peak}$ was 62dB(A).)

As V_{sf}, which is a dimensional value, is used as a parameter to calculate of SPL1 and SPL2, the model scale should be taken into account when considering the field scale. The characteristics of sound were determined by the relation between the height of the mouth section, $h_{s2}$and V_{sf}, when the depth of the mouth section, B_s, was the same. Therefore, the model scale was considered in proportion to h_{s2}. The sound pressure level was also thought to change due to the experiment scale. As a law of similarity did not exist, however, it was not taken into consideration in this study, even though it would be an underestimation.

Calculation of the front water level using multi-directional irregular waves

Using the numerical simulation of multi-directional irregular waves (Hiraishi et al., 1994), the changes in the water level in front of the breakwater were calculated. In the calculation, it was assumed that the water depth was constant. Changes in the water level were expressed by the following equation, with the endless straight breakwater on the x-axis.

$$\eta(x,t) = K\sum_{n=1}^{N_s} 2\frac{1+\cos(\theta_n - 90)}{2} \cdot a_n \cos(k_n x \cos\theta_n + \sigma_n t + \varepsilon_n) \tag{4}$$

Changes in water surface were calculated by the overlapping N_s of component waves in different wave directions, using the single summation method (Takayama et al., 1989). N_s was 500 and a_n, k_n, θ_n, σ_n and ε_n represent the half amplitude, wave number, wave direction, angular frequency and initial phase, respectively, of the n-th component waves.

Sound characteristics of multi-directional irregular waves on the breakwater

The breakwater used for the calculation was a composite breakwater with a crown height of 2.8 m and an water depth of 9.8 m. The height from the still-water level to the bottom of the mouth section, h_{s1}, was 1.3 m, the height of the mouth, h_{s2}, 0.5 m and the depth, B_s, 0.5 m.

The significant wave height that caused personal danger on this breakwater was estimated (Endoh et al. 1994). The significant wave height, H_{ss}, when a splash occurred over the breakwater, was 0.93 m, H_{so} when an overtopping wave occurs, was 1.26 m, H_{st} when a person is knocked out by the overtopping wave was 1.34 m and H_{sd} when a person is carried into the sea by the overtopping flow was 1.94 m.

The wave significant wave height that reached the mouth, H_{sm} was 0.64 m, assuming that the crown height of breakwater was h_{s1} in estimating the overtopping wave height H_{so}.

Figure 8 shows the equivalent noise level, SPL_{eq} (index showing the average sound pressure level of irregular noise), and the maximum sound pressure level, SPL_{peak}, on the breakwater. The condition that the principal wave direction was normally incident to the breakwater (θ=90°) and the significant wave height, $H_{1/3}$ was 0.35 to 2.3 m. In this figure, hardly any difference due to spreading parameter, S_{max}, was seen either in SPL_{eq} or SPL_{peak}. SPL_{peak} became greater than 56.5 dB(A) of sound pressure level of background noise, SPLB, when $H_{1/3}$ was over 0.6 m which was almost equivalent to H_{sm}. SPL_{eq} increased gradually. It was approximately 60 dB(A) at H_{ss} and 65 dB(A) at H_{so}, which were not much larger than SPLB. On the other hand, SPL_{peak} reached approximately 85 dB(A) at H_{ss} and was 23 dB(A) larger than $SPLB_{peak}$ of 62dB(A).

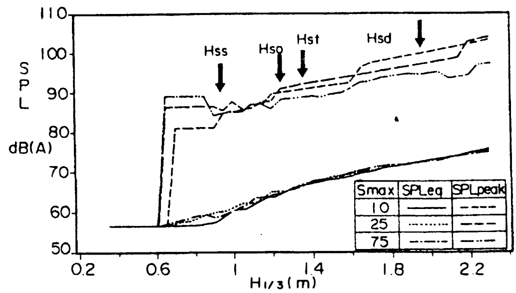

Figure 8 SPL_{eq} and SPL_{peak} with $H_{1/3}$

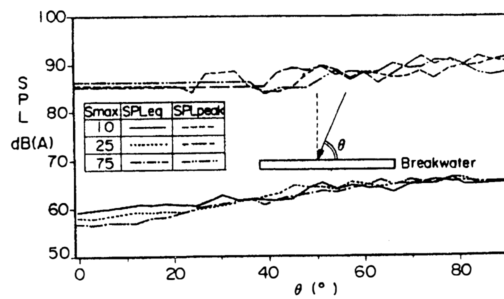

Figure 9 SPL_{eq} and SPL_{peak} with θ

Figure 9 shows the characteristics of sound in different wave directions. Calculation was conducted for H_{so} of 1.24 m, with the principal wave direction, θ, of 0 to 90°. Wave directions caused hardly any difference in the generated sound pressure level either in SPL_{peak} or SPL_{eq} when θ was 60 to 90°, but the level tended to decrease when θ was 60° or smaller. However, the decrease in sound by wave directions was not as significant.

SPLASH CHARACTERISTICS AT THE NOZZLE

Occurrence of splashes

Figure 10 shows the wave motions in the nozzle under the condition of the height from the still water level to the bottom of the mouth, h_{s1} = 18 cm, the height of the mouth, h_{s2} = 10 cm, the depth of the mouth, B_s =10 cm, h/L = 0.130 and H/h = 0.244. When the water level reaches the step section, it falls into the nozzle (1~2) and generates upward splashes when it collides with the back wall (3). The height of splash and wave runup from the bottom of the nozzle are is presented as η_s and η_w respectively. As shown in (4) to (6), the splash reaches higher than the wave runup.

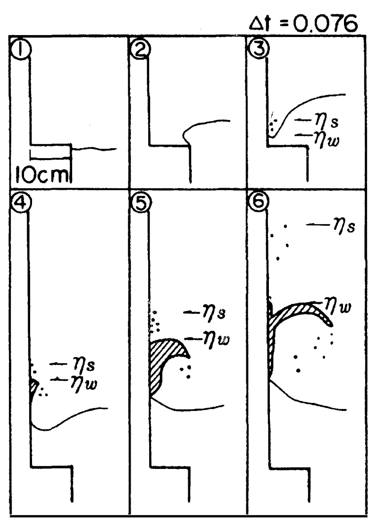

Figure 10 Wave Motion around Nozzle

Figure 11 shows the relation between η_s,η_w and the vertical velocity of the wave surface profile at the mouth bottom, V_{sf}. When V_{sf} reached approximately 50 cm/s, η_s and η_w started to increase and tended to peak when it exceeded 100 cm/s. There was no influence by h_{s1}. The relation between η_s and η_w can be formulated as a function of V_{sf}.

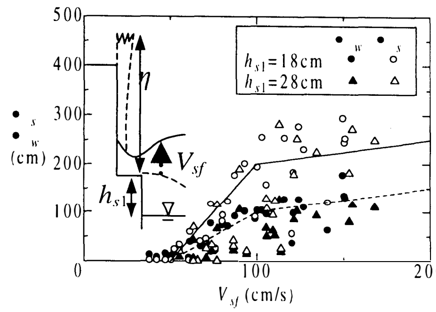

Figure 11 η_s and η_w with V_{sf}

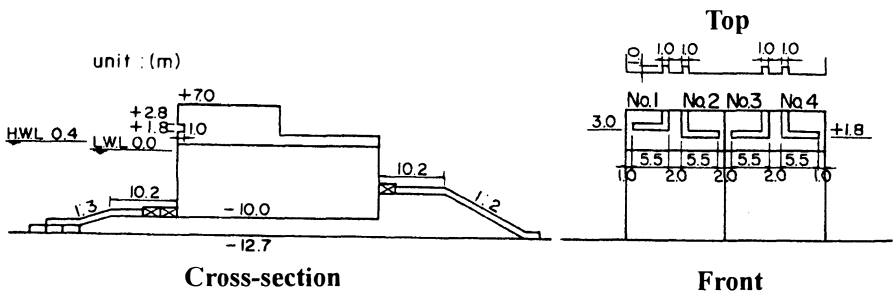

Figure 12 Cross-sectional, Front and Top Views of System

$$\eta_s(cm) = \begin{cases} 4.0V_{Sf} - 200 (50 < V_{Sf} \le 100cm/s) \\ 0.5V_{Sf} + 150 (V_{Sf} > 100cm/s) \end{cases}$$

$$\eta_w(cm) = \begin{cases} 2.0V_{sf} - 100 (50 < V_{sf} \le 100cm/s) \\ 0.5V_{sf} + 50 (V_{Sf} \ge 100cm/s) \end{cases} \quad (5)$$

Test installation site and observation method

Test installation of this system was conducted on a breakwater in Setana Port located on the Sea of Japan side of southern Hokkaido. The total length of this breakwater was approximately 600 m. The bottom slope was approximately 1/50 and the contour line was almost parallel to the breakwater.

Figure 12 shows the cross-sectional, front and top views of the system. The water depth, h, was 12.1 to 12.7 m and the crown height, h_c, 7.0 m. This breakwater had 4 systems. The height from the still water level to the bottom of the mouth, h_{s1}, was 3.0 m in No. 1 and 1.8 m in Nos. 2 to 4. The height of the mouth, h_{s2} and the depth of the mouth, B_s were all 1.0 m. Those values were 10 times larger than those of the model were.

The field observation was conducted in January and February 1997. The splash height was measured for 20 minutes every hour using a video camera placed on a quay 600 m away from the site. An ultrasonic wave gage (water depth of 53 m) was also installed 1.8 km offshore.

Occurrence of splashes

Photo 1 shows the splashes generated from the nozzle No. 2. White splashes are rising up to 4 m above the crown.

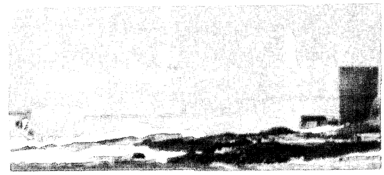

Photo 1. Splash Generation

Figure 13 shows an example of changes over time in the maximum splash height, η_{wmax}, in nozzles No. 2 to 4. The upper figure shows that the observed and calculated values correspond well with each other. The maximum wave height, H_{max}, and the maximum wave period, T_{max}, at the installation site of the breakwater were estimated from the field wave observation values. The vertical velocity of the wave surface profile at the mouth bottom, V_{sf}, was then calculated using the second approximation of the finite standing waves in Equation (6).

$$V_{sf} = \left(\frac{d\eta}{dt} \right)_{\eta = h_{s1}}$$
$$\eta = H \cos \sigma t + \frac{H^2}{8} k \frac{\cosh kh(2 + \cosh kh)}{\sinh kh} \cos 2\sigma t \qquad (6)$$

where, H is wave height, σ is angular frequency, k is wave number, t is time and h is water depth.

As the water-pillar type splashes shown in Photo 1 were seen in the field observation, η_w of wave runup in Equation (6) was used to calculate the splash height. As Equation (6) has a dimension, Froude similitude was used for field conversion.

The lower section of Figure 13 shows the maximum wave height, H_{max}, and the maximum wave period, T_{max}, during the 20-minute splash observation. The maximum wave height when wave overtopping occurred, H_{mo}, was 4.8 m on the test breakwater (Endoh et al., 1994). Splashes occurred at the site with less wave height than H_{mo}. Therefore, it would be possible to warn people before dangerous conditions occur.

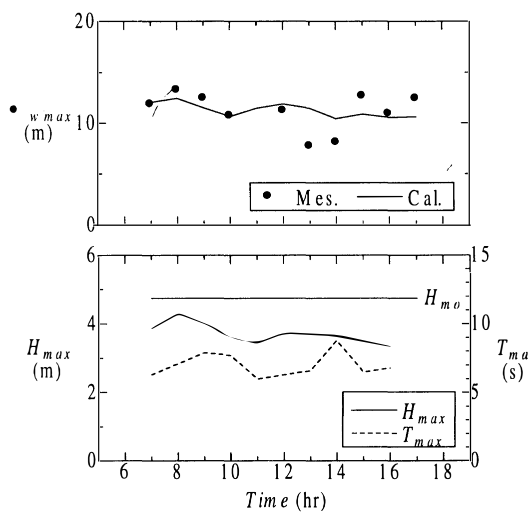

Figure 13 changes of η_{wmax} over time

CONCLUSION

This study proposed a new system to evaluate the level of danger from overtopping waves. Characteristics of sound and splash generated from the promenade breakwater warning system were examined by model experiments, a numerical simulation and field observation. The main conclusions are as follows:

1) Four phases in the sound pressure are generated by this system.

2) The peak of sound pressure level was formulated as a function of V_{sf}.

3) The numerical simulation of multi-directional irregular waves clarified the characteristics of the sound. The peak of sound pressure level was much larger than that of the back ground noise when a wave reached the mouth and the decrease in sound by wave directions was not as significant.

4) The heights of splash and wave runpu were formulated as a function of V_{sf}.

5) The splash was generated before wave overtopping occurred and its height calculated from wave conditions tended to agree well with field observation data.

When opening a breakwater to the public, it is necessary to make a variety of arrangements for the safety of users. This system is relatively easy to install and thought to be effective for safety measures.

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MASS PERTURBATION METHOD FOR DYNAMIC ANALYSIS OF OFFSHORE STRUCTURES

Kyu Nam Cho

Hong Ik University
Chochiwon, Chungnam, KOREA
kncho@wow.hongik.ac.kr.

ABSTRACT

The current work presents an analysis algorithm for the modal analysis for the dynamic behaviors of offshore structures with concepts of mass perturbation term. The mass perturbation method by using the term, presented in this paper offers an efficient solution procedure for dynamic response problems of offshore structures. The basis of the proposed method is the mass perturbation concepts associated with natural frequencies and mode shapes and mass properties of the given structure.

The mathematical formulation of the mass perturbation method is described. New solution procedures for dynamics analysis are developed, followed by illustrative example problems which deal with the effectiveness of the new solution procedures for the dynamic analysis of offshore structures. The solution procedures presented herein is compact and computationally simple.

INTRODUCTION

Determining of the dynamic characteristics of a structure can be done by the normal mode method. The deflection of a point in the structure is expressed in terms of normal modes of the structure and the normal coordinates.

Mode superposition method for determining the motion characteristics of offshore structures such as offshore platforms are well established. The method to figure out the forced response of the structure is based on the natural frequencies and corresponding mode shapes obtained from an eigenvalue analysis of the structure. The equations of the motion in uncoupled form by using the calculated natural frequencies and mode shapes can be derived and solved. The forced response of the given structure can be obtained by superposition of the selected number of mode shapes. However, it is difficult and ambiguous to decide the number of participating mode shapes in the mode superposition method in the response analysis.

In order to overcome these difficulties, an efficient analysis algorithm for the modal analysis for the dynamic behaviors of offshore structures is proposed. The basis of the proposed method is the mass perturbation concepts.

The mass perturbation term provides information of the dynamic characteristics of the structure. The term indicates how much the corresponding mode influence into the response of the structure. Large value of the mass perturbation term means that small structural change is associated with the motion. Small value of the term means that large structural change is associated in the motion response. Thus, the value of mass perturbation term associated with specific mode can be the indication of the participation of that mode in the forced response. The method discussed herein requires only calculation of natural frequencies and mode shapes from an eigenvalue analysis of the objective structure, which is supposed to be dynamically responded due to the exciting forces.

The modal contribution depends on the system's natural frequencies as well as the excitation frequency. The failure of large structures is an awesome possibility under resonance due to the exciting frequency. Structures are designed to escape the resonance in the early design stage. Thus in this paper the effects of the system's natural frequency are mainly considered. (API RP 2A, 1993)

In the following section, the mathematical formulation of the mass perturbation method is described. Solution procedures for the dynamic analysis are developed, followed by illustrative numerical examples.

THEORY

Background

The differential equations of motion in the x coordinate system in the matrix form is (Clough and Penzien and Anderson, 1975, 1984)

$$[M]\{\ddot{x}(t)\}+[C]\{\dot{x}(t)\}+[K]\{x(t)\}=\{F(t)\} \quad (1)$$

Where
$[M]$: mass matrix of structure
$[C]$: damping matrix of structure
$[K]$: stiffness matrix of structure
$\{F(t)\}$: column matrix of external forces
$\{x\}$: column matrix of displacement of structure
$\{\dot{x}\}$: column matrix of velocity of structure
$\{\ddot{x}\}$: column matrix of acceleration of structure

Equation (1) represents a system of differential equations, the solution of the differential equations can be obtained by two methods. They are direct integration procedure and mode superposition procedure. However, the procedures for the solution of differential equations can become very expensive when the order of the matrices is large.

The mode superposition method is characterized by the fact that the differential equations of motion are decoupled when the displacements are expressed in terms of the normal modes. Thus, the algebra required in the solution is considerably reduced. Furthermore, proper selection of participating modes in the displacements results in a drastic reduction of computation efforts without losing the precision. The question is how to decide the number of participating mode shapes in the mode superposition method in the response analysis.

Mathematical development

An eigenvalue analysis of a structural system including offshore structure can be defined by

$$[M]\{\ddot{x}(t)\}+[K]\{x(t)\}=0 \tag{2}$$

which produces the eigenvectors $\{\Phi\}$ and the natural frequencies $\{\omega^2\}$
The modal perturbation method offers an approximate solution of the redesign problem (Sandstorm and Cho, 1982, 1989)
The perturbation equation can be derived as below,

$$[\Phi]^T[\Delta K]\ [\Phi] - [\Phi]^T[\Delta K]\ [\Phi]\{\omega^2\} = [\Delta] \tag{3}$$

where $[\Delta] = \begin{cases} M_i \Delta\omega_i^2 & i = j \\ M_j C_{ij}\left(\omega_i^2 - \omega_j^2\right) & i \neq j \end{cases}$

$$[M'] = [M] + [\Delta M]$$
$$[K'] = [K] + [\Delta K]$$
$$\lfloor \omega'^2 \rfloor = \lfloor \omega^2 \rfloor + \lfloor \Delta\omega^2 \rfloor$$
$$[\Phi'] = [\Phi] + [\Delta\Phi] = [\Phi]([I] + [C])^T$$

Perturbation influence terms can be defined

$$P_e^k = \{\Phi\}_j^T[K_e]\{\Phi\}_i,$$
$$P_e^m = -\omega_i^2\{\Phi\}_j^T[M_e]\{\Phi\}_i \tag{4}$$

where $[K_e]$ $[M_e]$ represent the stiffness matrix of element e and the mass matrix of element e, respectively. (Sandstorm and Kim, 1982, 1988)

The perturbation influence terms provide important information for redesign process. Large value for P means that small structural change would be required to meet the design specifications. Small values for P means that large structural changes would be required.

The perturbation influence terms can be used to identify structural elements which have any effect on the modal changes.

Methodology

To use the perturbation idea we can define new mass perturbation term which provides information of the dynamic characteristics of the structure.

$$P_i^m = -\omega_i^2\{\Phi\}_j^T[M]\{\Phi\}_i \tag{5}$$

The term indicates how much the corresponding mode influence into the response of the structure.
Large value of the mass perturbation term means that small structural change is associated with the motion. Small value of the term means that large structural change is associated in

the motion response. The value of mass perturbation term associated with specific mode can be the indication of the participation of that mode in the forced response.

The amount of contribution of the specific mode in the total motion response can be represented

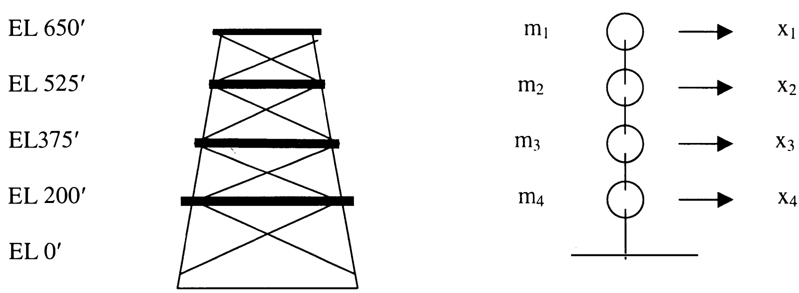
$$E_i = \frac{\left| \left(P^m\right)_i^{-1} \right|}{\left| \sum_{r=1}^{n} \left[\left(P^m\right)^{-1}\right]_r \right|} \tag{6}$$

Thus this equation gives the guidelines to decide the number of participating mode shapes in the mode superposition method in the response analysis.

APPLICATIONS

Jacket structure

A simple model (Yun et al, 1985) of an offshore tower is used to evaluate the application of the mass perturbation method in the response analysis of the structure.



(a) Real Structure (b) Idealized Model

Figure 1. Jacket Structure Model

In modeling the jacket structure, we have $m_1 = 9.6 \times 10^5$, $m_2 = 1.16 \times 10^5$, $m_3 = 1.5 \times 10^5$, $m_4 = 1.76 \times 10^5$ (slugs), and corresponding mass and stiffness matrix of the modal are as follows.

$$[M] = \begin{bmatrix} 9.6 & 0 & 0 & 0 \\ 0 & 1.16 & 0 & 0 \\ 0 & 0 & 1.5 & 0 \\ 0 & 0 & 0 & 1.76 \end{bmatrix} \times 10^5 \quad \text{(slugs)}$$

$$[K] = \begin{bmatrix} 1.961 & -2.742 & 0.5046 & 0.2503 \\ -2.742 & 5.597 & -3.042 & 0.1698 \\ 0.5046 & -3.042 & 5.063 & -2.568 \\ 0.2503 & 0.1698 & -2.568 & 4.691 \end{bmatrix} \times 10^7 \quad \text{(lb/ft)}$$

Eigenvalue analysis gives the following results.

$T_1 = 3.82$ sec, $T_2 = 0.68$ sec, $T_3 = 0.34$ sec, $T_4 = 0.24$ sec

$$[\Phi] = [\{\Phi\}_1, \{\Phi\}_2, \{\Phi\}_3, \{\Phi\}_4]$$

$$= \begin{bmatrix} 1.00 & -0.1303 & 0.0774 & -0.0475 \\ 0.7068 & 0.5545 & -0.8453 & 1.00 \\ 0.3998 & 1.00 & -0.4977 & -0.7211 \\ 0.1414 & 0.7882 & 1.00 & 0.2722 \end{bmatrix}$$

With API Recommended Spectrum and RMS (Route Mean Square) Methods, we have a typical design response as follows.

$$\begin{Bmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \end{Bmatrix} = \begin{Bmatrix} 4.831 \\ 3.420 \\ 2.020 \\ 0.825 \end{Bmatrix} \text{ (inch)}$$

For the above model, the responses for each mode can be obtained.

1st mode, $$\{X\}_1 = \begin{Bmatrix} 4.83 \\ 3.41 \\ 1.93 \\ 0.68 \end{Bmatrix} \text{ (inch)}$$

2nd mode, $$\{X\}_2 = \begin{Bmatrix} -0.07 \\ 0.31 \\ 0.58 \\ 0.46 \end{Bmatrix}$$

3rd mode, $$\{X\}_3 = \begin{Bmatrix} 0.005 \\ -0.06 \\ -0.03 \\ 0.07 \end{Bmatrix}$$

4th mode, $$\{X\}_4 = \begin{Bmatrix} -0.0005 \\ 0.01 \\ -0.007 \\ 0.003 \end{Bmatrix}$$

In this case, it is found that the precise real response can be obtained just by employing only 1st and 2nd modes in the modal analysis. Relevant mass perturbation terms $(P^m)_i^{-1}$ corresponding to each mode can be obtained based on the method developed here. (Table 1) In this case the mass perturbation terms indicate that 96% of the forced response may be obtained by using 1st and 2nd modes. Real response indication of this problem is 94.25%

with 1st and 2nd modes participation in the modal analysis.

This means that the mass perturbation term can be an indication of the mode participation in the modal analysis.

Table 1. Mass perturbation terms and its contribution for Jacket analysis

10^7	$\left\|(P^m)_i^{-1}\right\|$	$\left\|\sum (P^m)_r^{-1}\right\|$	$\left\|\frac{(P^m)_r^{-1}}{\sum (P^m)_r^{-1}}\right\|$
1 st mode	139.6	161.03	86.69%
2 nd mode	14.85	161.03	9.22%
3 rd mode	3.83	161.03	2.38%
4 th mode	2.75	161.03	1.71%

Two degrees of freedom spring-mass system

A two degrees of freedom spring-mass system is used to demonstrate the usage of the method. The equation of motion is as follows. (Brebbia and Walker and Yun, 1979, 1985)

$$\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}\begin{Bmatrix} \ddot{X}_1 \\ \ddot{X}_2 \end{Bmatrix} + 0.01\begin{bmatrix} 3 & 2 \\ 2 & 6 \end{bmatrix}\begin{Bmatrix} \dot{X}_1 \\ \dot{X}_2 \end{Bmatrix} + \begin{bmatrix} 2 & 2 \\ 2 & 5 \end{bmatrix}\begin{Bmatrix} X_1 \\ X_2 \end{Bmatrix} = \begin{Bmatrix} f_1(t) \\ f_2(t) \end{Bmatrix}$$

Eigenvalue analysis gives

$\omega_1^2 = 1$ $\quad \Phi_1 = \begin{Bmatrix} 1 \\ -0.5 \end{Bmatrix}$

$\omega_2^2 = 6$ $\quad \Phi_2 = \begin{Bmatrix} -0.5 \\ 1 \end{Bmatrix}$

Modal analysis gives the response of the system,

$$\begin{Bmatrix} X_1(t) \\ X_2(t) \end{Bmatrix} = q_1(t)\{\Phi\}_1 + q_2(t)\{\Phi\}_2$$

And the decoupled equation of motion is,

$$\ddot{q}_1(t) + 0.02\dot{q}_1(t) + q_1(t) = \frac{1}{\sqrt{5}}(2f_1(t) - f_2(t))$$
$$\ddot{q}_2(t) + 0.07\dot{q}_2(t) + q_2(t) = \frac{1}{\sqrt{5}}(f_1(t) + 2f_2(t))$$

For arbitrary value of f_1 (t), f_2 (t) , the total response of the system can be,

$$\begin{Bmatrix} X_1 \\ X_2 \end{Bmatrix} = \begin{Bmatrix} 1.25 \\ 7.5 \end{Bmatrix}$$

For this model, the response for each mode can be expressed,

1st mode, $$\{X\}_1 = \begin{Bmatrix} 1.2096 \\ 0.6075 \end{Bmatrix}$$

2nd mode, $$\{X\}_2 = \begin{Bmatrix} 0.135 \\ 0.27 \end{Bmatrix}$$

In this case, it is found that the precise response can be obtained by using 1st mode only. Relevant mass perturbation $(p^m)_i^{-1}$ terms, corresponding to each mode can be obtained. (Table 2) In this case mass perturbation terms indicate that 86% of the forced response is obtained by using 1st mode only. Real response indication of the problem is to be 80% with 1st mode participation in the modal analysis. This example shows that the precision is a little bit going down.

Table 2. Two d. o. f. mass-spring model and mass perturbation terms and contributions

	$\left\|(P^m)_i^{-1}\right\|$	$\left\|\sum (P^m)_r^{-1}\right\|$	$\left\|\dfrac{(P^m)_r^{-1}}{\sum (P^m)_r^{-1}}\right\|$
1 st mode	0.80	0.93	86%
2 nd mode	0.13	0.93	14%

CONCLUSION

The current work develops an analysis scheme for the modal analysis of dynamic behaviors of offshore structures with many degrees of freedom. The basis of the proposed scheme is the application of the mass perturbation concepts associated with natural frequencies and mode shapes and mass matrix of the given structures. It is found that the mass perturbation value gives the guideline for selecting the necessary mode shapes in carrying out the modal analysis. The mathematical formulation of the mass perturbation method is developed. New solution procedures for the typical structural problems are demonstrated. The solution procedure presented herein is compact and computationally much simpler. Example problems, which demonstrate the effectiveness of the new procedures, were followed, and the method is proved to be efficient and reliable.

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FEASIBILITY STUDY OF SEMISUBMERSIBLE TYPE VLFS

K. Yoshida, K. Iijima and H. Suzuki

Dept. of Environmental and Ocean Engineering, The University of Tokyo
Tokyo, JAPAN
k-yoshida@naoe.t.u-tokyo.ac.jp

ABSTRACT

A numerical analysis method of semisubmersible type VLFSs in waves was developed in the University of Tokyo. This is a linear analysis method which is easy to be used for design purpose. In this paper, several series calculations on responses of semisubmersibles subjected to waves were executed. Based on these results, considerations are given on characteristics and feasibility of two kinds of large sized semisubmersibles such as column type and column-lowerhull type.

INTORDUCTION

A numerical analysis method of semisubmersible type VLFSs in waves was developed in the University of Tokyo, in which, based on Goo's method (Goo et al., 1990), two kinds of technologies were newly added in order to extend the calculation ability to a case with very large number of unknowns. It is the Goo's method that combines Kagemoto theory (Kagemoto et al., 1986), which can effectively treat with hydrodynamic interaction between multiple floating bodies subjected to wave, with the three dimensional SDM (Singularity Distribution Method) for allowing arbitrariness of floating body configuration.

Two kinds of technologies newly added are sub-structure method and group body concept. In the method adopted in this paper, structure is firstly divided into sub-structures. Each sub-structure is supposed to consist of several number of group bodies, while each group body is composed of several number of floating bodies. Here, group body is a new concept defined as a unit that can be treated hydrodynamically as if one body. By introducing the group body concept, the number of floating bodies is virtually reduced. In Fig.1, comparison of hierarchies of the Goo's method and the method adopted in this paper is shown.

Verification of the present method was carried out by comparison of calculated responses obtained from executions of a number of calculations with experimental responses measured in tank tests (Iijima et al., 1997). As these comparisons showed considerably good coincidence between calculations and experiments, it was concluded that the analysis method used in this paper has a good enough accuracy with respect to responses such as displacements, strains of structural members and tension fluctuations in case of tension leg mooring.

A plan of execution of systematic calculations on responses of semisubmersible type VLFSs in waves was made and calculations were executed considering circumstances where characteristics of their responses have scarcely clarified yet. Two kinds of semisubmersibles are treated: one is a semisubmersible whose deck structure is supported by columns solely (hereafter, this kind of semisubmersible is simply called column type in this paper) and the other is one whose deck structure is supported by columns and lowerhulls(hereafter, column-lowerhull type). An example of the former is a semisubmersible proposed in a conceptual design for the first stage construction plan of Kansai International Airport by Japan Shipbuilding Industries Association in 1979. That of the latter is a semisubmersible in the conceptual design of MOBs proposed by several marine industries in USA and Europe to US Navy during this one decade.

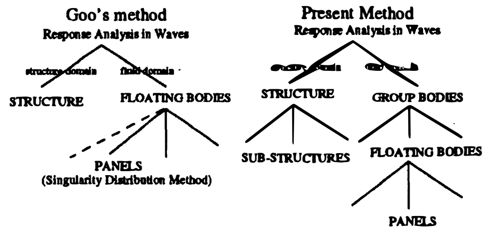

Figure 1. Hierarchy of present Modeling of Floating Structures

RESPONSE CHARACTERISTICS OF COLUMN TYPE MODELS

The column type model for systematic calculations in this paper is shown in Fig. 2 and the principal dimensions of two kinds of these type models are shown in Table 1. Average weight including upper structures, runway pavement and the floating structure itself per unit area is assumed 18000 Pa or 1.8 tf/m^2.

The deck structure is discretized into approximately 2300 beam elements, 2300 nodes. Each node has six DOFs. The number of panels for SDM on all the columns is approximately 230000 because the number of columns is 2898 in this design and the number of panels per one column is assumed approximately 80. This total number of unknowns is too large to execute usual computation. Therefore, by using two kinds of technologies proposed above, the problem can be reduced to 46 sub-structures and 322 group bodies. Each sub-structure has 50 elements (see Fig. 3). Each group body composed of 9 bodies with 710 panels. 7 terms are used for cylindrical function series expansion. Therefore, the total number of unknowns of the equations solved simultaneously is less than 4000. However, it must be noted that there is such a possibility that accuracy of numerical analysis may not be enough due to lack of number of expansion terms in certain frequencies, where some more number of terms should be assumed in order to get solutions with higher accuracy.

Table 1. Principal Dimensions of Column Type Semisubmersibles

TYPE	COLUMN SUPPORTED (2898 columns)
Disp./Deck Area	18 (kN/m^2)
Draught	9.0 (m)
Deck	Length Model- 1:1080 (m) Model-2:4140 (m) Width 30 (m) Height 6.0 (m)
Columns	OD 15 (m) Minimum length between columns 30 (m)
EI_y *as one beam* EI_z *as one beacm*	7.95 x 10^{13} (Nm^2) 2.58 x 10^{17} (Nm^2)

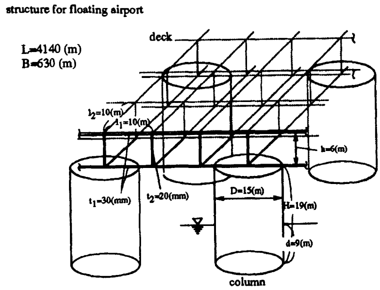

Figure 2. Deck Structure and Column of Column Type Semisubmersible for Floating Airport

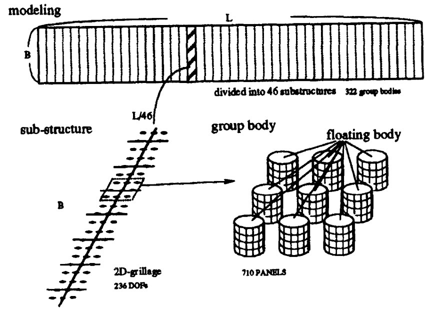

Figure 3. Numerical Modeling of Column Type Semisubmersible

In Fig. 4, frequency response curves of horizontal displacements at the three points of the deck structure in the oblique sea condition (60 degree from head sea) are shown. As amplitudes of the displacements at P3 and P5 are almost of same magnitude, the curves can not be distinguished from each other in the figure. The amplitudes of these points have a tendency of increasing in the range of low frequency. This tendency is based on usual quasi-static response of floating structure subjected to waves with very long wave length. The peak at wave frequency ω=0.45 rad/sec corresponds to the natural frequency of the 1st order horizontal bending mode of the model. Internal forces of deck structure treated in this numerical analysis are defined in Fig. 5.

In Fig. 6, frequency response curves of bending stress and axial stress at the center of the deck structure in head sea condition are shown. The highest peak of bending stress appears at wave frequency ω=0.21 rad/sec in this figure. In the range lower than this frequency, the bending moment caused by curvature of the wave slope is dominant, while in the higher range, the bending moment caused by external force distribution is dominant, which is almost independent of deflection. In this higher frequency range, the moment decreases with an increase of wave frequency due to cancellation of external forces with different phases. Thus, there appears the peak at the frequency where two ranges meet. This peak, which is significant from the view point of structural design of this type VLFSs, was named as the characteristic frequency (Suzuki et al., 1995).

On the other hand, responses at resonant frequencies are not outstanding in spite of the fact that there are many resonant frequencies corresponding to deformation mode in the range higher than the natural frequency ϖ_0 of resonance with heave mode. This result implies that large resonance responses do not occur in case of column type very large semisubmersibles. Therefore, we may choose such a design that resonant frequencies corresponding to deformation modes fall into the dominant frequency range of wave spectra.

In Fig. 7, frequency response curves of stresses at two points of the deck structure of the model in oblique sea condition (60 degree from head sea) are shown. As seen in this figure, the characteristic frequency is important in bending moment even in oblique sea condition. The most distinct difference between Fig. 6 and 7 is that a hump appears around frequency ω=0.6 rad/sec in Fig. 7. This peak is caused by coupling of bending moment due to vertical deflection in longitudinal direction with that in transverse direction which takes its maximum at this frequency. Moreover, it can be mentioned from this figure that stress due to axial force caused by overall horizontal bending is not negligible because the peak at ω=0.45 rad/sec corresponds to natural frequency of 1st order horizontal bending mode as noted before. Although horizontal bending does not play an important role in usual structural design, it may play an important role in some case of column type very large semisubmersibles.

When periodic arrays of columns are subjected to a plane incident wave, standing waves with large amplitude appear in a similar manner to resonance at particular frequencies which are decided by relation between incident wave length and column spacing. This interesting phenomenon was confirmed by tank test following computed result carried out in advance (Yoshida et al.,1994) and this was theoretically explained (Maniar et al.,1997). It is expected that at this frequency, a strong dynamic pressure may be generated on wall structures of columns. According to the present numerical results, at the wave frequency ω=0.85 rad/sec which satisfies the condition $kl=\pi/\sqrt{2}$ (k:wave number, l:column spacing), dynamic pressure attains three times as much as that expected from incident wave elevation. This value is less than that predicted by diffraction problem because there are other components such as radiation effects. Peaks in Fig. 6 at ω=1.06 rad/sec and ω=1.40 rad/sec correspond to resonant frequencies of different modes.

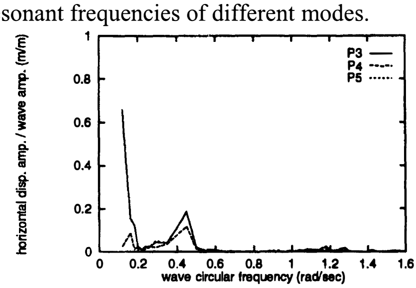

Figure 4. Frequency Response Curves of Deck Horizontal Displacements of Column Type Semi-submersible in Oblique Sea Condition

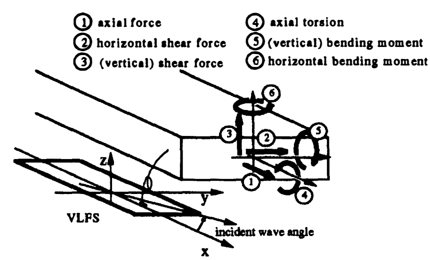

Figure 5. Definition of Internal Forces of Structural Members in Present 3-D Frame Model

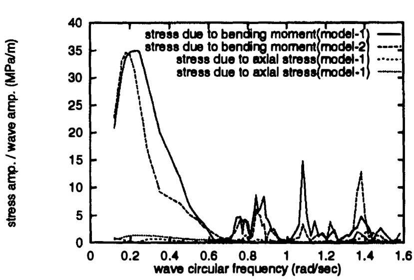

Figure 6. Frequency response Curves of Bending and Axial Stresses at the Center of Deck of Column Type Semisubmersible in Head Sea Condition

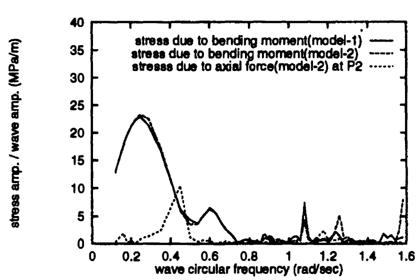

Figure 7. Frequency Response Curves of Bending and Axial Stresses at the Center of Deck of Column Type Semisubmersible in Oblique Sea Condition

RESPONSE CHARACTERISTICS OF COLUMN-LOWERHULL TYPE MODES

As to the column-lowerhull type model, more systematic calculation plan was programmed and executed. First of all, the original semisubmersible was decided, which is shown in Fig. 8 and principal dimensions are given in Table 2. This is one of the typical semisubmersibles which consists of deck structure, two lowerhulls, eight columns and a number of braces. In numerical analyses carried out hereafter, this original structure is divided into two sub-structures and each sub-structure is supported on two group bodies.

Table 2. Principal Dimensions of Original Column-Lowerhull Type Semisubermsible

TYPE	2 Lower-Hulls, 8 columns
Displacement	200,000 (kN)
Draught	21.4 (m)
Deck	Length 91.4 (m) Width 56.4 (m) Height 3.0 (,)
Lower Hull L X B X D	91.4 (m) X 11.0 (m) X 6.7 (m)
Columns	Large (outer): OD 7.9(m) Small (inner): OD 5.8(m)
EI_y as one beam EI_z as one beam	2.22×10^{14} (Nm^2) 4.53×10^{14} (Nm^2)

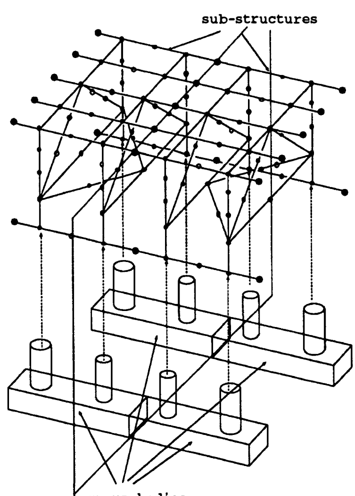

Figure 8. Sketch of Original Column-Lowerhull Type Semisubmersible and Modeling for Numerical Analyses

Each group body consists of two columns and half part of single lowerhull. Each sub-structure is modeled as 3D frame. Based on the original semisubmersible, two kinds of model series for numerical calculations were generated. One series was generated by connecting several original ones in longitudinal direction. As shown in Fig. 9, based on the original one (mono-ploid, 91.4m), four models for numerical calculations were generated, which are a model multiple twice (di-ploid, 182.8m), a model multiplied by six times (hexa-ploid, 548.4m) and a model multiplied by ten times (deca-ploid, 914m). The other series was generated by connecting several models modified and multiplied by 14 times (1280m) in transverse direction. Some modifications of principal and structural dimensions of the original model are necessary to avoid excessive stresses due to tremendously long length of this 14 times model (T-1 model). Using this T-1 model, T-3 model was obtained by multiplying T-1 model transversely by three times. In the same manner, T-5 and T-7 models were obtained (see Fig. 10).

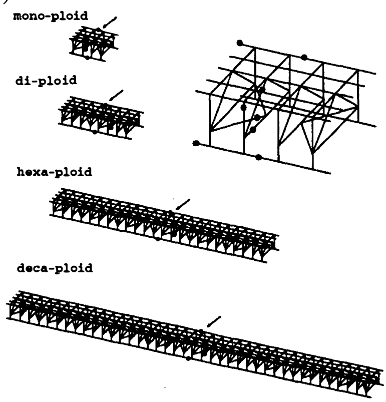

Figure 9. Schematic View of Four Kinds of Longitudinally Connected Column-Lowerhull Type Semisubmersibles

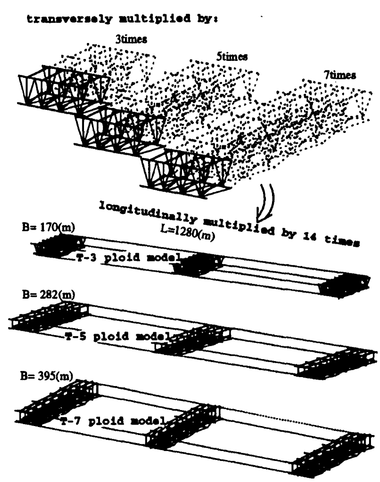

Figure 10. Schematic View of Three Kinds of Transversely Connected Column-Lowerhull Type Semisubmersibles

In Fig. 11, frequency response curves of deck axial stress at the midship of four kinds of models connected in longitudinal direction in head sea condition are compared. The peaks of the response curve of deca-ploid at wave frequencies ω=0.56, 0.58, 1.10 rad/sec correspond to natural frequency of 1st order axial torsion mode, 1st order vertical bending mode and 2nd order vertical bending mode, respectively. In case of very slender column-lowerhull type semisubmersibles like deca-ploid, as shown in this figure, resonances at natural frequencies are apt to show very large responses. Taking a number of other calculated results on this calculation series into consideration, resonances in vertical and longitudinal bending mode, in horizontal bending mode and in axial torsion mode show large responses which make structural design almost impossible. This fact implies that column-lowerhull type slender semisubmersibles like deca-ploid or even hexa-ploid are not feasible from the structural design view point.

Fig. 12 shows frequency response curves of axial stress of the four kinds of T series models in oblique sea condition. It can be clearly seen from this figure that the narrow models like T-1 or T-3 may not be feasible but the wide models like T-7 may be feasible as intuitively expected.

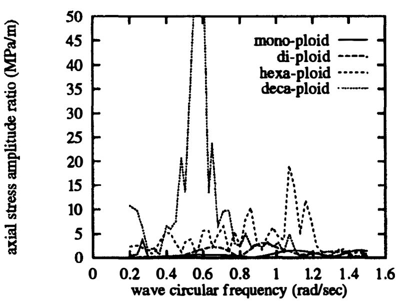

Figure 11. Frequency Response Curves of Bending and Axial Stresses at the Center of Deck of Column Type Semisubmersible in Head Sea Condition

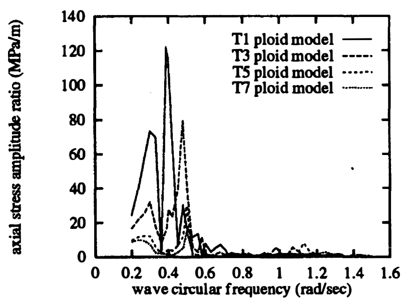

Figure 12. Frequency Response Curves of Deck Axial Stresses at the Ctr. of Transversely Connected Column-Lowerhull Type Semi-submersibles in Oblique Sea Condition

CONCLUDING REMARKS

A numerical analysis method of semisubmersible type VLFSs in waves was developed in the University of Tokyo. Although not explained in this paper, taking hydrodynamic and hydroelastic interactions simultaneously into account, this method can execute calculations of linear responses even in case of very large number of unknowns. Initial design is usually carried out based on linear analysis results. Therefore, it can be said that feasibility of semisubmersible type VLFSs may be discussed based on systematic series calculation program well prepared in advance. In this paper, following this context, some series calculations were carried out. Characteristics and feasibility of semisubmersible type VLFSs were discussed based on the calculated results. The significant but temporal conclusions are as follows: Feasibility of large sized column type semisubmersibles are controlled by magnitude of vertical bending moment corresponding to characteristic frequency. Comparing with column-lowerhull type, column type is apt to be more feasible. On the other hand, a very slender column-lowerhull type like MOB may be difficult to be safe in severe sea condition even in case of one structure without mechanical connectors. However, large sized column-lowerhull type may be feasible as one structure if they are designed to be wide enough.

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MEASUREMENT AND MODELLING OF WAVE PROPAGATION AND BREAKING AT STEEP CORAL REEFS

Stanislaw R. Massel and Richard M. Brinkman

Australian Institute of Marine Science
Townsville, Queensland, AUSTRALIA
r.brinkman@aims.gov.au

ABSTRACT

Coral reefs are globally under increased pressure from the impacts of human development. The need for sustainable development strategies has lead to demands to provide a sound engineering and environmental basis for infrastructure developments in reefal areas. This can only be achieved through a comprehensive understanding of the physical processes that shape the reef environment and control its ecology. Three processes dominate hydrodynamics of reefs: wave shoaling and breaking, wave set-up and wave-induced flow over the reef. This paper presents the results of extensive field observations, numerical studies and laboratory experiments of wave transformation, breaking and wave-induced flow over coral reefs. Field observations demonstrate the significance of wave processes in reef circulation. Wave transformation on the steep reef slope is modelled using the extended refraction diffraction equation, recently developed by Massel (1993), and numerical results compare well with laboratory studies.

INTRODUCTION

Coral reefs occur in the tropical regions of the Pacific, Indian and Atlantic Oceans in the form of fringing reefs surrounding islands, barrier reefs or separate atolls and island reefs (Veron, 1986). Increased economic pressure for development, increased impact from land-based and marine industries, and increased access to coral reef areas have all lead to demands to provide a sound engineering and environmental basis for infrastructure developments in reefal areas. This can only be achieved through a comprehensive understanding of the physical processes that shape the reef environment and control its ecology. Wave action is a significant contributor to these processes. Energy of waves propagating over the reef slope and water turbulence associated with wave breaking is responsible for reef zonation and segregation of organisms. Waves which shoal over the reef slope and are transformed on the reef platform impose forces on reef structures and organisms that inhabit the wave-swept zone of the reef. Moreover, water movement and the resulting replenishment of food and oxygen is essential for the development and maintenance of a healthy reef ecosystem.

This paper presents the results of extensive field observations, numerical studies and laboratory experiments of wave transformation, breaking and wave-induced flow over coral reefs. Wave transformation on the steep reef slope is modelled using the extended refraction diffraction equation, recently developed by Massel (1993). The wave prediction model allows for refraction and diffraction of waves at steep bottom slopes and energy dissipation due to wave breaking and bottom friction. Laboratory studies of wave transformation over simulated reefs are presented and compared with numerical predictions. Field observations are presented to demonstrate the significance of wave processes in reef circulation.

FIELD STUDIES

A study to observe wave induced reef circulation was undertaken at Ningaloo Reef, the largest fringing coral reef system in Australia, which extends 300 km along the Western Australian coast. Ningaloo Reef runs approximately parallel to the coast and is punctuated by deep, narrow channels and separated from the coast by wide (200—1000 m) lagoons. The reef is exposed to oceanic swell from the Indian Ocean. A location map of the study site is shown in Fig. 1.

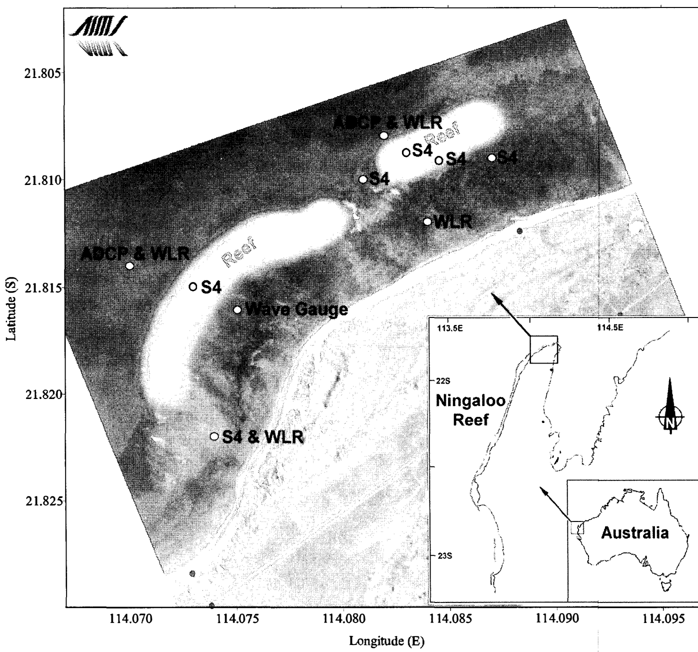

Figure 1. Locality map and instrument sites

The study site contained two reefs running parallel to the shore, separated from the coast by a shallow lagoon approximately 500 m wide. The lagoon was between 1 and 3 m deep and open at both north and south ends. Seaward of the reefs the water depth was $\approx$10 m, and a deep channel ran between the two reefs seaward from the lagoon. An observational instrument array consisting of three RDI Acoustic Doppler Current Profilers, six InterOcean S4 Vector Averaging Current Meters, one WHISL SeaPac 2100 Wave Gauge, four Water Level Recorders and one Waverider buoy was operational for fourteen days November and December 1997. Instruments sites are shown in Fig 1.

Bathymetry data was recorded throughout the study region using a downward looking ADCP mounted on a small boat, and coupled to a GPS positioning system. Meteorological data was obtained from an automatic weather station south of the study site. Typical reef profiles for both reefs are shown in Fig. 2. Both reef faces had slopes of approximately 1 to 25 and rose from a depth of 10 m to between 0 m and 1 m on the reef top.

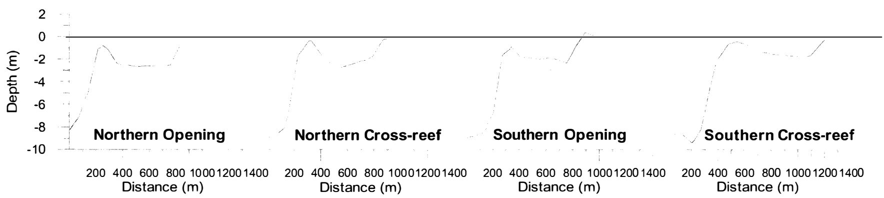

Figure 2. Typical reef profiles

Figure 3 presents observed currents at five locations in the study site, tidal elevation and wind velocity. A consistent flow over the reef top into the lagoon is evident at Site 1. Currents through the deep channel (Site 2) and through the southern opening of the lagoon (Site 4) were directed out of the lagoon, regardless of the phase of the tide. Current direction through

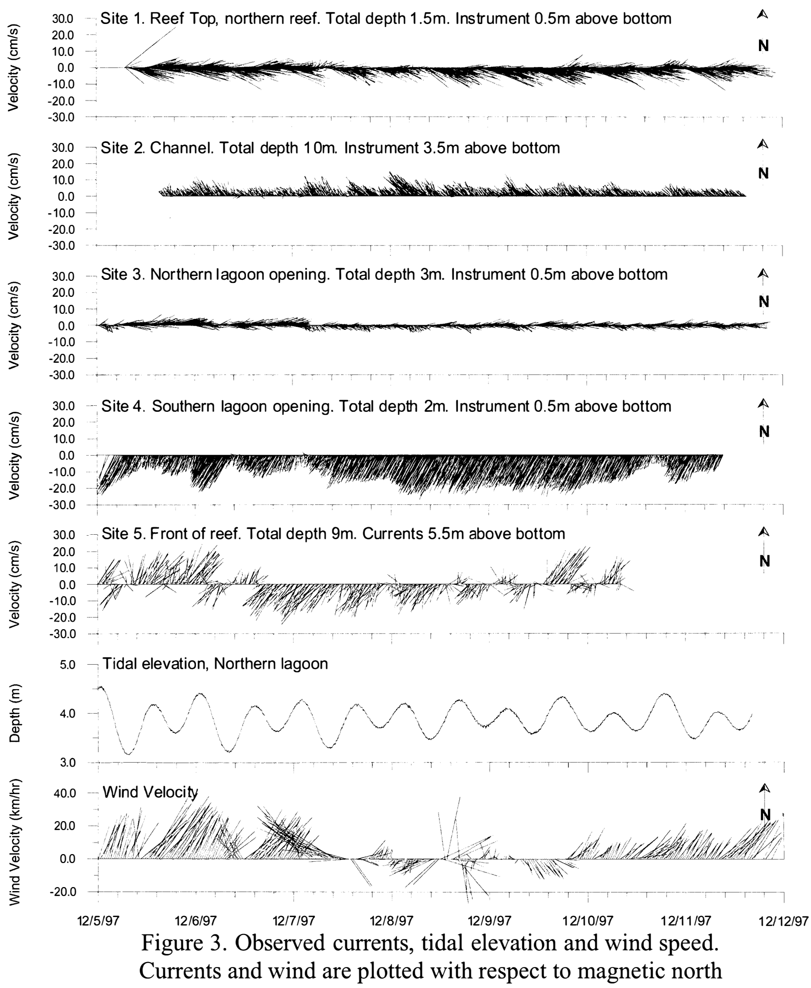

Figure 3. Observed currents, tidal elevation and wind speed. Currents and wind are plotted with respect to magnetic north

the northern lagoon entrance (Site 3) is more variable, and rarely into the lagoon (towards the west-southwest). In particular, flow through the southern opening of the lagoon is invariably against the prevailing strong south-westerly winds. In contrast, currents in front of the reef (Site 5) display some periodic reversing and amplitude modulation consistent with tidal flow. Current meter data shows no significant evidence of inflow into the lagoon other than via flow over the reef top.

Fringing coral reefs act in a similar way to offshore breakwaters and protect the shallow lagoonal regions from the full force of oceanic swells. For typical offshore breakwater systems high wave setup occurs landward of the channels between the breakwaters while low wave setup occurs behind the breakwaters. This generates both longshore currents towards the areas behind the breakwaters, and rip currents towards the breakwaters, which in turn produce an offshore current through the gap. It is realistic to assume that this circulation mechanism is present, however in our study region it may not be significant when compared to the circulation driven by flow over the reef top, for a number of reasons. Firstly, the ratio of the width of the gap to the total length of reef is small, and consequently the region of wave setup, and the magnitude of this setup will also be small. Secondly, as the reefs are submerged, the onshore current over the reef top may be large enough to reverse any offshore rip currents and longshore currents towards the area behind the reef.

Although a water mass balance for the reef-lagoon system, calculated from observed currents, is not presented here, it is apparent from the combined flux of water out of the lagoon that wave pumping over the reef top is a very significant process for reef circulation. The continual outflow of water from the lagoon, independent of tidal phase, would indicate that wave pumping is a more important process than tidally driven circulation in reef flushing.

THEORY

On the reef slope, water depth varies substantially and the refraction and diffraction effects cannot be neglected. In order to account for these effects, an approach based on the mild-slope equation (Berkhoff, 1972) is used. Massel (1993, 1996), using the Galerkin-Eigenfunction Method, extended the applicability of the mild-slope equation for steep slopes. The resulting refraction-diffraction equation includes the higher order terms and evanescent modes as well as the energy dissipation due to breaking and bottom friction. Thus, relatively rapid and physically realistic undulations in water depth at coral reefs can be accommodated. For an elongated, uniform reef, the governing velocity potential Φ(x,z,t) can be represented in the form:

$$\Phi_2(x,z,t) = \frac{-igH_i}{2\omega} Z(z)\varphi(x)\exp(-i\omega\, t) \tag{1}$$

in which:

$$Z(z) = \frac{\cosh k(z+h)}{\cosh kh} \tag{2}$$

and

$$\frac{d^2\varphi}{dx^2}+(CC_g)^{-1}\frac{dCC_g}{dx}\frac{d\varphi}{dx}+\left[k^2(1+\psi)+i\gamma k-\chi^2\right]\varphi=0, \tag{3}$$

the x-axis is directed normal to the reef, the z-axis is directed upwards with the origin at the still water level, φ is the non-dimensional wave height, and C and C_g are the phase and group velocities, respectively. The coefficient ψ represents the influence of bottom slope and bottom curvature, i.e.:

$$\psi=E_1(kh)\left(\frac{dh}{dx}\right)^2+E_2(kh)\frac{d^2h}{dx^2}, \tag{4}$$

in which $E_1(kh)$ and $E_2(kh)$ are complicated functions of (kh) and can be found elsewhere (Massel, 1994, 1996). The damping factor γ expresses the dissipation due to wave breaking and bottom friction, i.e.:

$$\gamma=\gamma_b+\gamma_f \tag{5}$$

in which:

$$\gamma_b=\frac{8<\in_b>}{\rho g C_g H^2} \text{ and } \gamma_f=\frac{8<\in_f>}{\rho g C_g H^2} \tag{6}$$

where $<\in_b>$ and $<\in_f>$ represent the average rates of energy dissipation (per unit area) due to wave breaking and bottom friction, respectively. For parameterisation of both dissipation mechanisms see, for example, Massel (1996) or Massel and Gourlay (1998).

The shoaling, refraction, diffraction and dissipation processes induce spatial changes in the radiation stress, resulting in changes of mean sea level. Longuet-Higgins and Stewart (1964) have shown that a balance of the sea level gradient and the gradient of radiation stress takes the form:

$$\frac{dS_{xx}}{dx}+\rho g(h+\overline{\eta})\frac{d\overline{\eta}}{dx}=0 \tag{7}$$

in which $\overline{\eta}$ is the deviation of mean sea level (wave set-up or set-down) due to wave action, and S_{xx} is a radiation stress tensor component:

$$S_{xx}=E\left(\frac{3}{2}m-\frac{1}{2}\right)+\frac{1}{2}Em\cos\Theta \tag{8}$$

where:

$$E=\frac{1}{8}\rho g H^2 \tag{9}$$

$$H=H_i\sqrt{[\Re\varphi(x)]^2+[\Im\varphi(x)]^2} \tag{10}$$

$$\text{and} \quad m = \frac{1}{2}\left(1 + \frac{2kh}{\sinh 2kh}\right) \tag{11}$$

in which $\Re$ and $\Im$ are the real and imaginary parts of the complex function φ.

The third important hydrodynamic process at coral reefs is flow over the reef induced by breaking waves. Due to the relatively shallow water depth on the reef, the set of governing equations takes the form (Massel 1998):

$$\frac{d[U(h+\overline{\eta})]}{dx} = 0 \tag{12}$$

$$\rho g(h+\overline{\eta})\frac{d\overline{\eta}}{dx} = -\frac{dS_{xx}}{dx} - \frac{1}{2} f_r \rho |u_w| U \tag{13}$$

in which U is the depth-averaged water velocity, u_w is the bottom wave orbital velocity, ρ is the water density and f_r is the bottom friction coefficient. Equation (12) represents the conservation of water mass and Equation (13) is the balance of the sea level gradient, the radiation stress gradient and the resistance due to bottom friction. Combining both equations provides the final equation for $\overline{\eta}$ (Massel, 1998):

$$\begin{aligned} &\frac{d^2\overline{\eta}}{dx^2} + \left[\frac{2}{h+\overline{\eta}}\frac{dh}{dx} - \frac{F_1}{(h+\overline{\eta})^2} - \frac{1}{r}\frac{dr}{dx}\right]\frac{d\overline{\eta}}{dx} \\ &-\frac{1}{h+\overline{\eta}}\left[\frac{dF_1}{dx} + \frac{F_1}{h+\overline{\eta}}\frac{dh}{dx} - \frac{F_1}{r}\frac{dr}{dx}\right] = 0 \end{aligned} \tag{14}$$

where:

$$F_1 = -\frac{1}{\rho g}\frac{dS_{xx}}{dx} \quad \text{and} \quad r = \frac{f_r |u_w|}{2g} \tag{15}$$

In this equation it was assumed that $\left(\frac{d\overline{\eta}}{dx}\right)^2 \approx 0$. For arbitrary bottom shape, equation (14) can only be solved numerically (Massel, 1998). In the next Section, an example of the solution of Equation (14) for the simpler case of a plane bottom slope is demonstrated.

LABORATORY EXPERIMENTS

Coral reef hydrodynamics presents considerable difficulties for physical and numerical modelling due to their steep bottom slopes, complex bathymetry, and large and non-uniform bottom roughness. Therefore, experimental and theoretical papers dealing with waves on reefs are not numerous. Gourlay (1994; 1996a,b; 1997) in a series of papers reported the results of very comprehensive laboratory studies on reef hydrodynamics. A summary of the results of these experiments has been presented by Gourlay (1996b) and will be not given here. We only note that the reef profiles used in experiments represented a wide range of reef types and profile shapes, with half the prototype reefs being fringing reefs, and the remainder being platform reefs. Geographically, half of the prototype reefs represented reefs in the Great Barrier Reef off northeastern Australia; others are on islands in the Pacific and Indian Oceans. More details on reef geometry and laboratory models can be found in other papers by Gourlay (1996a,b). For the purpose of this study we concentrate only on two well documented laboratory experiments: the Hayman Island reef model (Gourlay, 1994), and the model of an idealised reef (Gourlay, 1996a).

Hayman Island is a continental island in North Queensland (Australia). The typical reef profile adopted for the experiments is shown in Fig. 4(a). The reef face has a slope of 1 to 4.5 and rises from a depth of 19 m or 21 m, while the water depth at reef edge varies from 3.1 m to 5.1 m depending on the tidal level. The reef-top is initially sloping but the slope reduces away from the edge until the reef-top becomes horizontal 170 m from the reef edge. The total reef width is of the order of 800 m. The incident deep-water wave height used in experiments varies from 1.02 m to 3.61 m and the wave period is in a range from 3.8 s to 6.8 s.

Another model configuration and experimental results for wave transformation at an idealised two-dimensional reef model have been described by Gourlay (1996a). The profile of the idealised reef is shown in Fig 5(a). A 400 mm high horizontal model reef with a particularly absorbent 1 to 1 face slope has been constructed. The sea bottom in front of the reef has a slope 1 in 84 and the effective reef height is 320 mm. The width of reef top is about 15 m. Wave periods of 1.48 s and 1.10 s have been used and deepwater wave height varied from 41 mm to 218 mm. Water depth over the reef top varied from zero to 0.1 m.

Massel and Gourlay (1998) give a more comprehensive description of laboratory experiments on coral reefs.

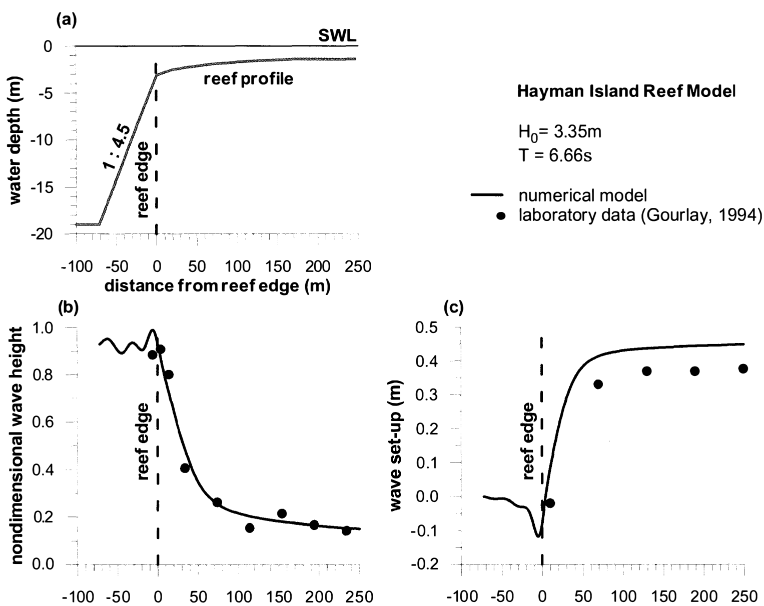

Figure 4. Comparison of numerical and experimental data for Hayman Island Reef. (a) model reef profile, (b) non-dimensional wave height and (c) wave set-up

COMPARISON OF THEORETICAL RESULTS WITH LABORATORY EXPERIMENTS

In Fig.4 (b) an example of attenuation of wave height over a distance of 300 m from the reef edge is shown. Agreement between numerical and experimental results is very good. An oscillation in wave height at the front of the reef is due to partial reflection of waves from the reef structure. Waves are plunging on reef edge and dissipate almost all of their energy within 100 m of the reef edge. The reflection coefficient is very small, $K_r = 6.2\%$, and transmission coefficient, $K_t = 18.7\%$. This means that about 96% of wave energy is dissipated by wave breaking.

In Fig.4(c) an example of the wave set-up distribution on the reef top, corresponding to the incident wave conditions shown in Fig.4 (b), is given. As expected, the model predicts small, negative set-up in the vicinity of wave breaking and an increased water level on the reef top. The agreement between calculated and experimental set-up is very good for smaller wave heights. For larger incident waves, although the trend is the same, calculated values are higher than the experimental data. One reason for this discrepancy may be the bottom friction coefficient, which has been assumed in the model as 0.01. This value is only an estimate of the real bottom friction, which is unknown for coral reefs.

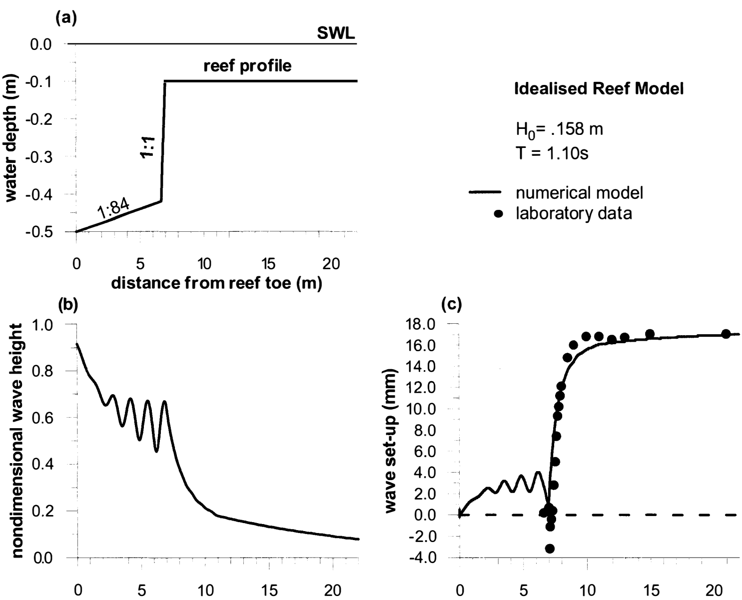

Figure 5. Comparison of numerical and experimental data for an idealised reef. (a) model reef profile, (b) non-dimensional wave height and (c) wave set-up

An example of wave transformation on the idealised reef is shown in Fig.5. Numerical calculations start at the reef toe where energy dissipation due to bottom friction increases and breaking begins. As a result, wave height decreases over the front slope of the reef and over the reef top. The oscillations in wave height are a result of the partial reflection of the approaching waves. Figure 5(c) illustrates the corresponding set-up on the reef-top. Because wave height continually decreases, set-down does not occur, and set-up gradually increases to its maximum value which is reached at approximately 3 m from the reef edge. At larger distances from the reef edge, wave height remains almost constant and the set-up also does not change. The oscillations in set-up result from the oscillations of wave height (and radiation stress) at the reef front.

In order to gain an insight into the wave-induced flow over the reef, we considered the simplified case of a reef with plane front and rear slopes (Fig. 6), instead of solving the full Equation (14) for a reef with random bathymetry. Assuming that set-up is only a small fraction of water depth, i.e. $h+\overline{\eta}\approx h$, and that through the surf zone the wave amplitude remains as a constant proportion of the water depth, then an analytical solution of Equation (14) can be obtained. In Fig.6 the resulting set-up, flow velocity and flow discharge are presented for a reef with front and rear slopes 1:5 and 1:8, respectively, and incident wave period of 5 s.

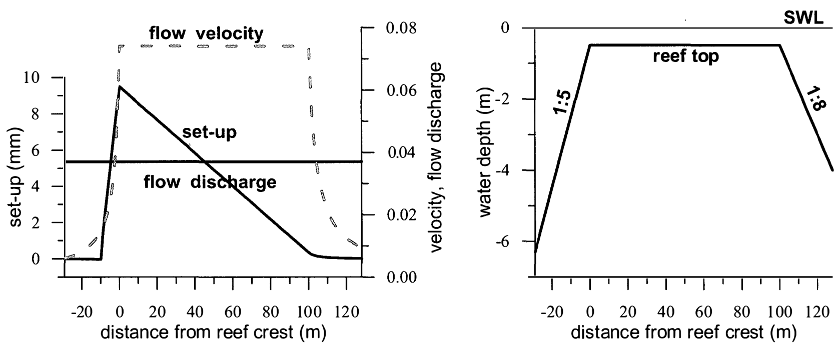

Figure 6. Calculated flow and setup over an idealised reef

CONCLUSION

In this paper the results of extensive field observations and laboratory and numerical modelling of waves propagating over steep coral reefs are presented. Three processes dominate hydrodynamics of reefs: wave shoaling and breaking, wave set-up and wave-induced flow over the reef. Field experiments clearly demonstrate the three-dimensional pattern of the wave field in the vicinity of the reef, and indicate the significance of flow over the reef in driving reef circulation. For an approximate estimation of wave behaviour at steep coral reefs, a theoretical two-dimensional model was briefly presented. Model predictions, in terms of wave height and set-up distributions, agree well with laboratory measurements. Furthermore, the first results of numerical calculations of wave-induced flow are also given.

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APPLICATION OF SALT INTRUSION MODEL TO EVALUATE IMPACTS OF INTERBASIN FRESHWATER TRANSFER

Gamble M. Sisson and Albert Y. Kuo

Virginia Institute of Marine Science
Gloucester Point, Virginia, U.S.A.
sisson@vims.edu
kuo@vims.edu

ABSTRACT

A proposal to withdraw freshwater from the Mattaponi River, a tributary of the York River in Virginia, USA, requires assessment of its environmental impact: how it may alter the salinity regime and thus affect existing biota throughout the York River system. To determine this alteration quantitatively requires use of a salt intrusion model, which incorporates the mass-balance equation, averaged over a tidal cycle, and solved numerically by an implicit finite difference scheme. Transport of salt within the model takes place by advection and dispersion. The constants in the formulation of the dispersion coefficient were adjusted by aligning model predictions with observed data for a 3-year calibration period.

The predictive capability of the model was demonstrated by running the model over a long period. Upstream daily discharge records (supplied by USGS) spanned a 46-year period (1942-1987), and this became the simulated period for the "historic" model run. Observation data were available for the 15-year period 1971-1986 and these were used to assess the aforementioned predictive capability. The model was then run over this same 46-year period using the proposed freshwater withdrawal scenarios to determine the nature of changes to the salinity regime. A statistical package was developed to process model results specifically focusing on predicted periods of stress to the existing freshwater marshes in the estuarine system. The primary conclusion from this comparison is the effect of withdrawal is far less than the inter-annual variability of salinity, and thus ecological effects would be minimal.

INTRODUCTION

The concern of Newport News Waterworks in Virginia that this municipality will have a water shortage as early as the year 2010 has led to its proposal to construct a 617 hectare (1,526 acre) reservoir in nearby King William County. The reservoir would hold some 49.4 million cubic meters (13 billion gallons) of water, mostly drawn from the Mattaponi River, a tributary of the York River, at a rate of up to 3.29 m^3/sec (75 million gallons per day). After usage, the withdrawn water would be discharged into the James River, thus resulting in an interbasin water transfer. The approval of the project has occurred at the state level by the State Water Control Board and the Department of Environmental Quality (DEQ), but it must also occur at the federal level by the U.S. Army Corps of Engineers. Many environmental groups are clearly in opposition, including the Sierra Club, the Southern Environmental Law Center, and the Chesapeake Bay Foundation.

The environmental concerns of the project stretch beyond an adverse change to the salinity regime, and include destruction of hundreds of hectares of wetlands as well as specific habitats, such as osprey and bald eagle nests. The purpose of the present study, however, is restricted to addressing the long term effect on salinity distribution of the proposed freshwater withdrawal and its impact on the marsh vegetation within the York River system.

The York River system is one of the western shore tributaries of the Chesapeake Bay Estuary (see Figure 1). The propagation of the tide through the York River is unique in that at West Point, the location at which the two major tributaries (the Pamunkey and the Mattaponi) converge, the highly non-linear features of the tidal wave begin to manifest themselves as one moves upstream. Figure 1a shows the York River's location within the Chesapeake Bay system, whereas Figure 1b shows the locations within the York for which daily salinities are predicted by the model.

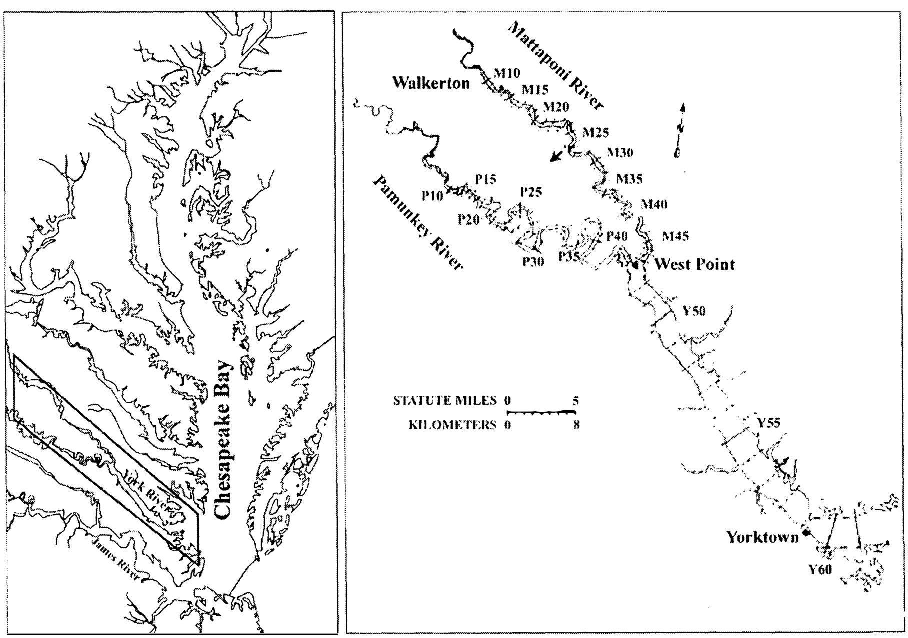

Figure 1a) Site map showing the location of the York River within the Chesapeake Bay and
1b) Locations of transects at which daily salinities are predicted by the model.

MODEL DESCRIPTION

The mechanisms of advection and dispersion account for the transport of salt within the salt intrusion model. This model incorporates the one-dimensional mass-balance equation, averaged over a tidal cycle, and solved numerically by an implicit finite difference scheme (Kuo and Fang, 1972). The mass-balance equation is shown on the next page:

$$\frac{\partial}{\partial t}(AS)+\frac{\partial}{\partial x}(AUS)=\frac{\partial}{\partial x}(AE\frac{\partial S}{\partial x}) \quad (1)$$

where t is time, x is distance along the river, A is cross-sectional area, S is salinity, $U=Q_f/A$, Q_f is the freshwater discharge, and E is the dispersion coefficient.

The dispersion coefficient may be described with a semi-empirical relationship:

$$E = bu_t\sqrt{A} + 77n\,h^{5/6}\overline{|u|}[1 + aS(\frac{Q_f}{Q_t})^{1/2}] \quad (2)$$

where u_t and Q_t are maximum tidal current and tidal discharge respectively, n is Manning friction coefficient, h is water depth, u is instantaneous tidal velocity, the overbar ($\overline{\ }$) denotes tidally averaged, and a and b are empirical constants. The first term in equation (2) represents tidal mixing (Kuo and Fang, 1972), the first part of the second term represents shear dispersion (Harleman, 1971), and the last part represents upriver transport by gravitational circulation (Wilbur and Kuo, 1987).

Several refinements were made to the model developed in 1972 prior to its application to the York River system for the evaluation of the King William Reservoir project. These include daily flow (instead of monthly flow) as input, allowing for freshwater withdrawal from any segment of the river system, and a new formulation for the dispersion coefficient (equation (2)). This new formulation includes the option of selecting the values of calibration constants (i.e., a and b as shown in equation (2)) for both of the two tributaries different from the values used to calibrate the York mainstem.

MODEL CALIBRATION AND APPLICATION

Calibration of the model involved the adjustment of constants a and b as shown in the dispersion formulation (equation 2). A comparison of prototype salinity distributions observed at slack tide to model predictions was first made using distance upstream as the x-axis in order to show the preliminary fit over the entire river length. This was done at several "snap-shot" points in time (e.g., model run days 51, 846, and 1210) as shown in Figures 2, 3, and 4. Preparation of the observation data included vertical averaging and segregation of SBE (slack before ebb measurements, denoted by triangles) and SBF (slack before flood measurements, denoted by squares) in Figures 2-5. The data points with distance less than 53 km are for the York River, whereas those with distance larger than 53 km are for the Mattaponi River. No calibration for the Pamunkey River was attempted. Figure 5 shows an example of the agreement between observed salinities and model predictions at a transect in the York River mainstem for the 3-year calibration period (1974-1977). The values of calibrated constants were determined to be: a=1.0 for the Mattaponi and the Pamunkey Rivers and a=10 for the York River, where the water column is partially stratified; b=1.0 for all three branches of the river. These are the typical values used in well-mixed to partially stratified coastal plain estuaries.

Once the model calibration was completed, the model was used to predict daily salinities at 102 locations throughout the York River system. The model simulation covers the 46-year period 1942-1987 for which daily discharge records are available at two upstream gauging stations in the Pamunkey and Mattaponi Rivers, respectively. This simulation was then also made with the proposed withdrawal of freshwater and the results were compared. The simulation of proposed

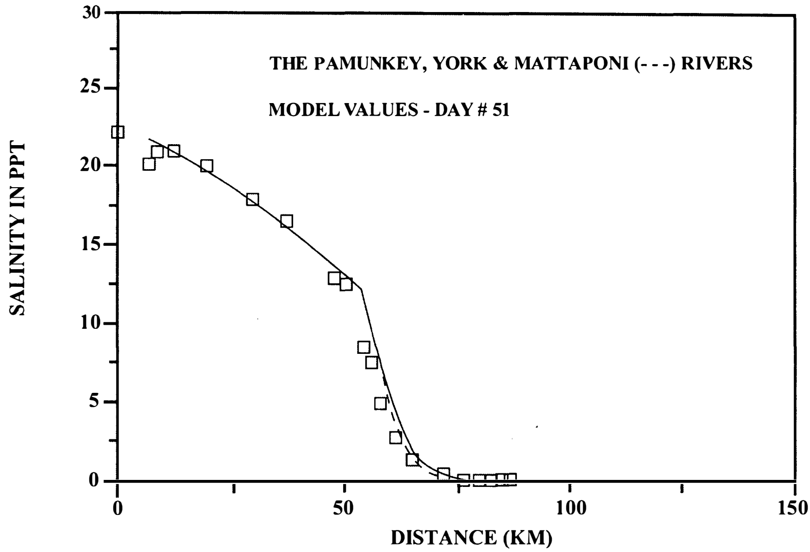

Figure 2. Observed salinities and model predictions versus distance from mouth of York River for model day #51. (□:SBF)

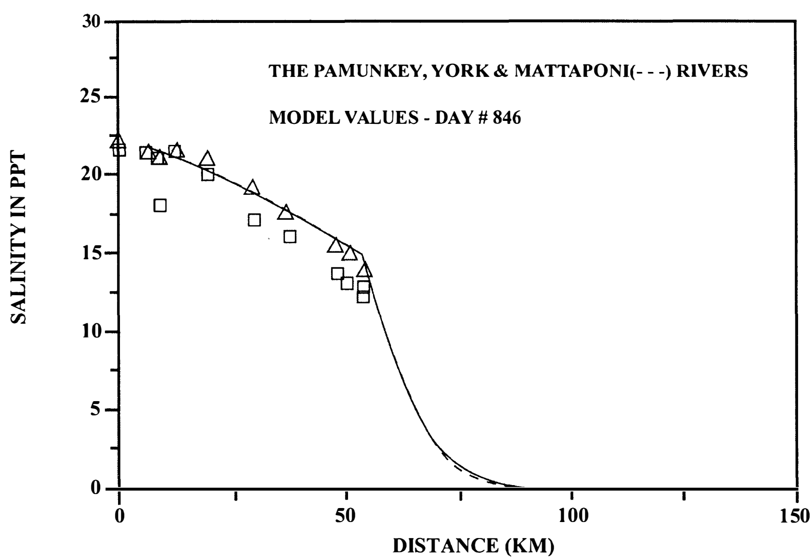

Figure 3. Observed salinities and model predictions versus distance from mouth of York River for model day #846. (□:SBF, Δ:SBE)

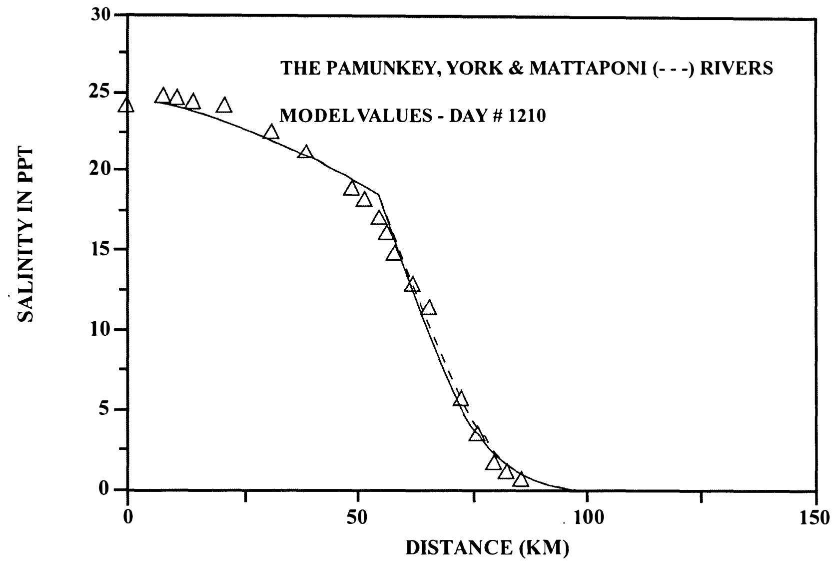

Figure 4. Observed salinities and model predictions versus distance from mouth of York River for model day $1210. (Δ:SBE)

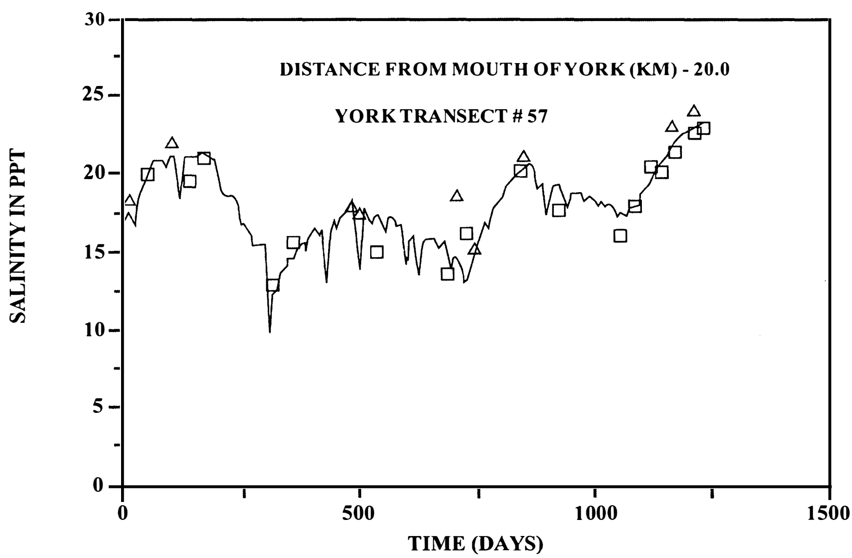

Figure 5. Observed salinities and model predictions at a tracnsect in the York mainstem shown over a 3-year period. (□:SBF, ΔLSBE)

withdrawal was run according to the strict guidelines that the minimum instream flow (MIF) would be maintained. Therefore, the allowable flow for withdrawal is constrained to be the excess of the natural flow (median value 15.6 cms for the Mattaponi River) above the MIF. The MIF was given two seasonal values: 8.70 cms for December - May, and 4.35 cms for June - November. The maximum withdrawal was conservatively set at 3.29 cms (75 mgd) and the average withdrawal was 1.88 cms (40 mgd).

MODEL RESULTS

The impact of the proposed withdrawal, averaged over all 46 years of the model simulation, is shown in Figure 6. A slight increase in salinity of less than 1 part per thousand (ppt) is shown over the region from the withdrawal location to approximately half the distance to the mouth.

Several statistical quantities were derived and comparisons were made between those with and without freshwater withdrawal. They included long-term mean, median, maximum, minimum, seasonal mean, percent of time salinity exceeds vegetation tolerance limits, etc.

Figure 7 is an example showing the time history of this impact on autumn salinity caused by withdrawal at a point several kilometers downstream of the proposed reservoir site. The inter-annual variability far exceeds the effect of withdrawal. Table 1 is another example summarizing statistical quantities at 5 locations in the Mattaponi River.

CONCLUSIONS

The statistical quantities of salinity distributions generated by the model for the historical and adjusted freshwater inflows were utilized by Hershner et al. (1991) to evaluate the potential impacts on the wetland vegetation on the Mattaponi River. They analyzed both the existing and historical vegetative community distributions and the relationship of these communities to the historical and withdrawal salinity patterns. Three types of plant communities, with the assumed maximum long-term salinity tolerance of less than 0.5 ppt, 0.5 ppt, and 5.0 ppt, were examined. The following major conclusions were derived:

1. There is only a slight increase in salinity in each river segment; little or no impact on existing vegetation is predicted.
2. Salinity at a selected up-river segment does not exceed the historical mean at the adjacent down-river segment: no up-river shifts in existing vegetation is expected.
3. There is no significant increase in the total number of days in which seasonal salinities exceeded the assumed maximum long-term salinity tolerances of each selected vegetation community.

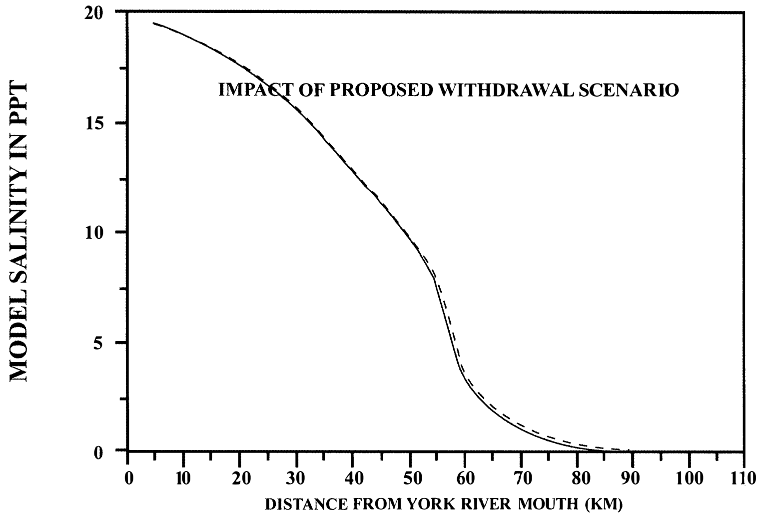

Figure 6. Long-term average of increased salinity (dotted line) due to withdrawal.

Summary of Model-Generated AUTUMN Salinity Data

Transect M39

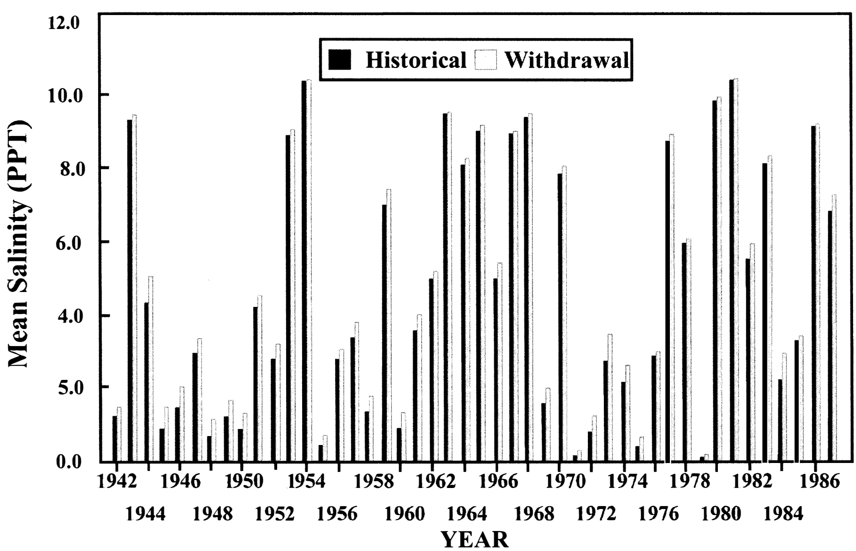

Table 1. Summary of Mattaponi River Salinity Modeling Results (540 month simulation - OCT 1942 to SEPT 1987).

River Station	WITH PUMPING (Y or N)	SUMMARY OF MONTHLY SALINITIES (ppt)			NUMBER OF MONTHS WITHIN SPECIFIED SALINITY RANGE			
		MEAN	MEDIAN	RANGE	< 0.1	0.1 - 0.5	0.5 - 5	> 5
8 M48 (West Point)	N	4.83	3.95	0 -15.03	36	57	217	230
	Y	5.07	4.25	0 -15.10	31	49	220	240
M42 (0.8 km upstream of Rt 645)	N	1.99	0.52	0 -11.67	194	73	191	82
	Y	2.25	0.78	0 -11.77	170	70	203	97
M36 (Melrose Landing)	N	0.61	0.01	0 - 7.46	346	69	111	14
	Y	0.72	0.03	0 - 7.60	319	78	123	20
M24 (Mantapike)	N	0.15	0.00	0 - 3.69	450	42	48	0
	Y	0.18	0.00	0 - 3.83	436	48	56	0
M10 (Walkerton)	N	0.01	0.00	0 - 0.71	523	16	1	0
	Y	0.01	0.00	0 - 0.76	520	18	2	0

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SYSTEM DESIGN OF AN AUTONOMOUS UNDERWATER VEHICLE FOR OCEAN RESEARCH AND MONITORING

Pan-Mook Lee, Yong-Kon Lim, Seok-Won Hong, Chong-Moo Lee, Bong-Hwan Jeon and Jong-Won Park

Korea Research Institute of Ships and Ocean Engineering
Taejon, KOREA
pmlee@mailgw.kimm.re.kr

ABSTRACT

An autonomous underwater vehicle, VORAM (Vehicle for Ocean Research And Monitoring), is developed in KRISO (Korea Research Institute of Ships and Ocean engineering) for the observation and investigation of sea-bed. This paper describes the configuration of VORAM and introduces a hybrid navigation system composed of integrated navigation sensors, communication systems, an underwater image communication system, and a robust digital controller based on discrete-time sliding mode control. The hybrid navigation system is developed to compensate the erroneous measurement from a super short baseline with the use of sensor fusion algorithm based on Kalman filter and fuzzy logic. Communication for sending commands and receiving data is carried out through the acoustic telemetry modem in deep sea, and through a radio frequency modem at sea surface. This paper introduces the acoustic image communication system that is under development for underwater image transmission. This paper also shows the experimental result of depth keeping control performed in a towing tank and the simulation of obstacle avoidance control with obstacle avoidance sonar and motion sensors.

INTRODUCTION

An autonomous underwater vehicle, named VORAM, is developed in KRISO for the observation and investigation of deep-sea. This paper presents the design and configuration of VORAM and introduces the specification of VORAM AUV. VORAM is equipped with a hybrid navigation system composed of a super short baseline (SSBL) and a motion reference unit (MRU), an acoustic telemetry modem (ATM), acoustic image communication system, obstacle avoidance sonar (OAS), an altitude sonar. VORAM is designed to be remotely controlled from a surface vessel with acoustic link. The AUV can also maneuver with pre-programmed mission.

VORAM AUV can be remotely controlled from the surface vessel with an acoustic link and be able to maneuver with pre-programmed mission, since the AUV is equipped with a hybrid navigation system and an acoustic telemetry modem. A robust digital controller, discrete-time sliding mode controller, is adopted to make the AUV stable. The vehicle can be controlled in real-time by an operator on a support ship via the acoustic link under system uncertainties and external disturbance.

Table 1. Specifications of VORAM AUV

Dimension	2.82 × 1.10 × 0.40 (L × W × H)
Weight in Air	357 Kg
Operating Depth	200 m
Speed	2.5 knots
Operating Time	4 hours
Battery	2 × 24V−38AH Lead−Acid
Thrusters	Two Horizontal, One Vertical Propeller - NACA66, 600 RPM , Diameter : 20.0cm BLDC motor, Resolver feedback
Elevators	NACA0016, 0.222 × 0.120 × 0.020 (s × c × t)
Communication	ATM-851 (Datasonics), 13 ~ 20 kHz, 1200 Baud max. RF-Modem at sea surface, 1200 Baud
Navigation	SSBL (LXT, ORE), Motion Reference Unit (MRU−5, Seatex)
CPU & O.S.	M68040(MVME162), VMEexec
Other Equipment	RFM, OAS, Altitude Sonar, SSS, Depth Sensor, Inclinometer, Compass, Speedometer, STD, Light, CCD, Image Communication Device, Weight Drops

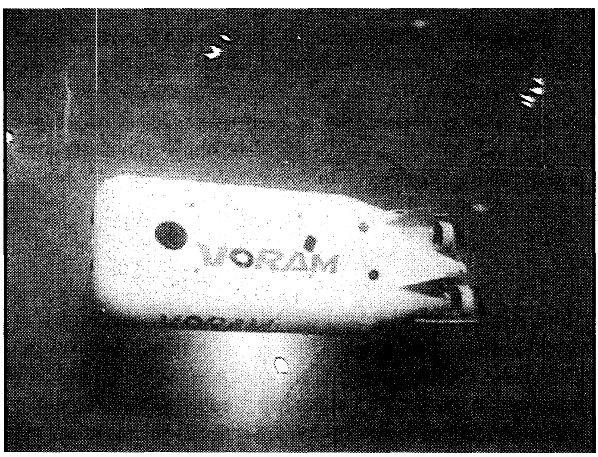

Figure 1. VORAM AUV in Ocean Engineering Basin in KRISO

The dimension of VORAM AUV is 2.82m in length, 1.10m in width, and 0.40m in height. It weighs 357 Kgs in air and has neutral buoyancy in water. Figure 1 shows the VORAM in tank test. The volume of VORAM in water is about 887 Kgs including the flooded seawater, which induces inertial force during the motion. The maximum speed in calm water is 1.25 m/sec. The specifications of VORAM AUV are given at Table 1, and the conceptual drawing and the arrangement of equipment are shown at Figure 2 and 3, respectively (KRISO report, 1997).

Two oil filled 24V-38AH batteries are used as power source of VORAM. The vehicle is controlled with two horizontal thrusters in horizontal plane, and with two elevators and one vertical thruster in vertical plane. The vertical thruster is used to generate pitch moment at low speed, and the elevators are used at high speed. The thruster is driven by a RPM controlled 120 Watt brushless DC (BLDC) motor with a maximum speed of 3000 RPM, which is equipped with an oil-filled resolver. A reduction gear is used to produce maximum thrust at 600 RPM on propeller. The elevator is controlled with a DC motor within a maximum range of ±30 degrees. The angle of elevator is measured by a potentiometer connected to the reduction gear shaft. Weight drop devices regulate the buoyancy of the vehicle, which can make the vehicle descend and ascend without power consumption.

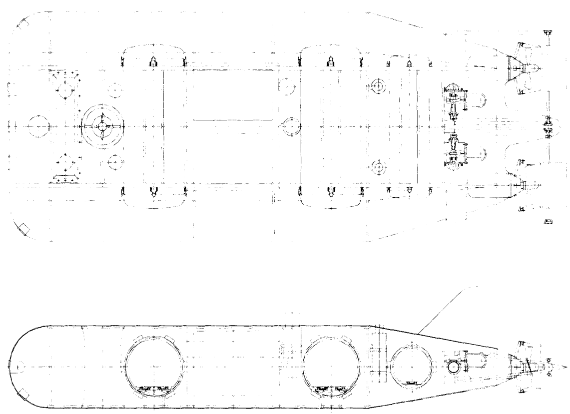

Figure 2. Schematic Drawings of VORAM AUV

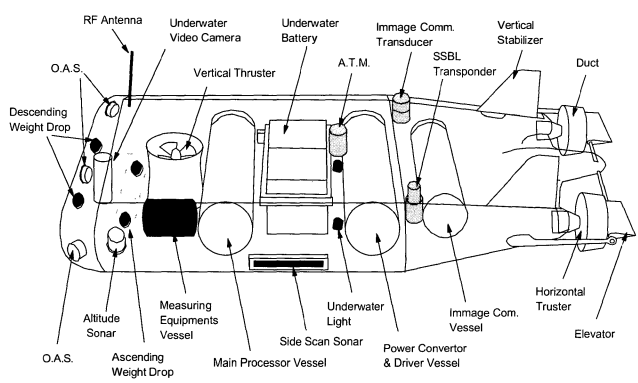

Figure 3. Arrangement of transducers and devices equipped on VORAM AUV

All electronic equipments are installed in four pressure vessels, which are designed to resist 200m water depth's pressure and fixed to two main longitudinal frames as shown in Figure 2. The first pressure vessel includes main computer system, analog circuits for measurement of vehicle's attitude, and I/O interface devices. The second includes electric devices for power conversion, BLDC motor drivers, elevator motor drivers, and other electronic circuits for emergency and seawater leakage detection. The third is for signal conditioning and processing circuits for underwater acoustic devices such as OAS and altitude sonar. The fourth is for an underwater image communication system under development. The AUV is covered with FRP shell to minimize drag force. A special emergency circuit is designed for safety. When the computer system is in malfunction, a counter circuit cleared by the CPU triggers the emergency circuit. An analog circuit monitors the state of the vehicle and also triggers the emergency circuit when leakage occurs in any pressure vessel or when the voltage of the battery drops.

SYSTEM CONFIGURATION OF VORAM AUV

A schematic diagram for the architecture of the AUV system is shown in Figure 4. Communication for sending commands and receiving data is carried out through the acoustic

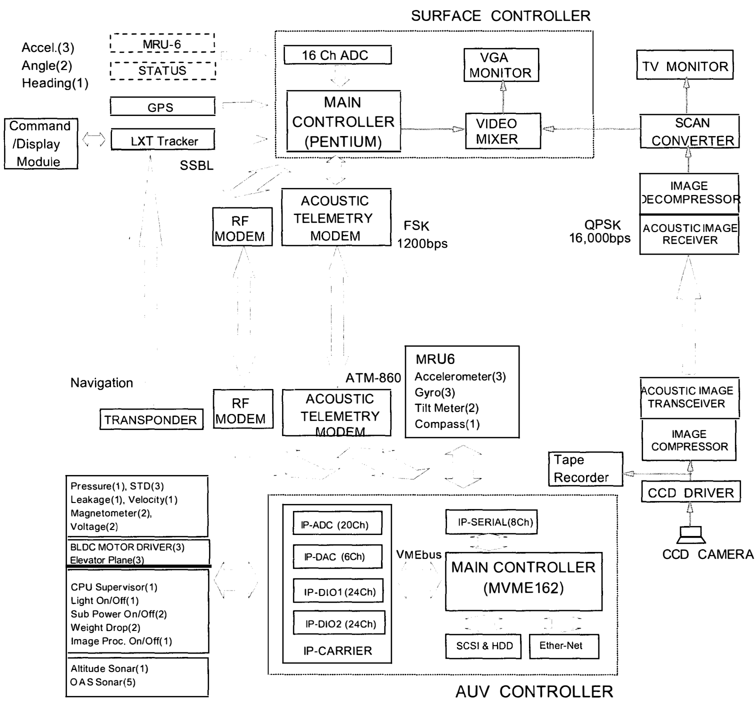

Figure 4. System configuration of VORAM AUV

telemetry modem, Datasonics ATM-851 (Datasonics, 1995), in deep sea, and through the radio frequency modem at sea surface. The ATM can communicate data upto 6000m distance and its baud rate is 1200 bps in normal condition. Baud rate of RF modem can be alternatively selectable to be 1200/9600 bps but fixed at 1200 bps.

Position is measured by SSBL-LXT (ORE, 1996) of surface ship. A transponder on surface ship transmits acoustic sonar signal to the AUV to acquire interrogation signals radiated from a transponder of the AUV. Since the position is obtained through calculation using slant angle and range, it is easily contaminated with environmental noises and surface ship motions. A hybrid navigation system was developed to compensate the erroneous measurement of AUV's position, which is measured with the SSBL, a flowmeter, two motion reference units and a sensor fusion algorithm based on fuzzy logic.

Motions and attitude of the vehicle are measured by a depth sensor, an altitude sonar, three accelerometers, two inclinometers, a magnetic flux gate type heading compass, and three rate gyros. Five OAS sensors are equipped to detect obstacles when the vehicle is in sea bottom following mode. Altitude sonar is equipped to measure the altitude from sea bottom, of which the measuring range can be regulated by adjusting the gain of automatic gain control circuit. Forward relative velocity of the vehicle is measured by a windmill type flowmeter. Temperature and salinity are measured with a temperature sensor and a salinity sensor respectively.

Main computer system of the vehicle is composed of following components: One VME bus interfaced Motorola 68040 33MHz MVME162 single board computer. Two 24 bits digital I/O boards to control digital devices such as light on/off, drop weight, propulsion power on/off, OAS channel & AGC gain selection, and recorder handling logic. One 12 bits 6 channel D/A converter for BLDC motor control and elevator control. One 12 bits 20 channel A/D converter to acquire data such as depth, accelerations, inclinations, angular rates through gyros, OAS range, altitude, and other analog data. One octal 232C card is installed for serial communication with RF modem, ATM, magnetic compass, and MRU. One IP carrier board interfaced with VME bus is adopted to extend the I/O boards. One-Giga bytes hard disk is installed in the vehicle to save position data, motion data, maneuvering/control data, image data and side scan data. Program can be run by down-loading to 1 Mbytes flash memory through an Ethernet link or to 4 Mbytes RAM through auto boot routine from the hard disk.

Main computer system of surface unit is a Pentium P/C, where ATM, RF modem, SSBL, and ship motion sensors are interfaced through an A/D converter and serial communication cards. This surface computer operates the vehicle through RF modem or ATM at discrete time interval.

A real-time operating system, VMEexec, is used to handle the multi-tasking control of multiple devices that have different bandwidth of operation. Modular tasks are programmed for all external interfaced devices such as ATM, RF modem, MRU, and magnetic heading sensors. Each task is controlled with event send/receive and semaphore handler, and main task generates or deletes the matched tasks for specific functions.

NAVIGATION SYSTEM

Hybrid Navigation System

The tracking system is composed of multiple-sensor systems such as an inertia measurement unit, a tri-axis magnetometer, a flowmeter, and a SSBL acoustic navigation system. The inertia sensor cannot be used for inertia navigation since drift effect of the error is relatively big due to low quality of the sensors, which provides 6 degree of freedom reference motions and attitude of the vehicle in body fixed coordinates. Although the SSBL can track the position of the vehicle, the signal is easily contaminated with the ship motions and ocean environmental noises. The flowmeter detects only forward directional velocity of the vehicle, which may provide somewhat inaccurate data due to the relative current velocities and noises.

The hybrid navigation system predicts the position of the vehicle by integration and filtering method using the reference motion data, the forward speed data, the attitude and the heading of the vehicle. The predicted position slowly drifts and the estimation error of position becomes larger due to the inaccuracy of the inertial sensors, the heading sensors and the flowmeter. On the other hand, the measured position of the SSBL is liable to change abruptly due to the corrupted data of the SSBL system in the case of low signal-to-noise ratio or large ship motions.

By introducing a sensor fusion technique with the position data from the SSBL system and those of the attitude heading flow reference system (AHFRS), the hybrid navigation system updates the three-dimensional position (Lee et al., 1997). A Kalman filter algorithm is derived on the basis of the error models for flowmeter dynamics, which uses the external measurement of the SSBL. It is assumed that the measurement signals in the attitude and the heading of the vehicle have no failure and have only white Gaussian noises and static offset errors. When failure occurs in the SSBL tracking system, the filter has to ignore the position signal from the SSBL to avoid the contamination of the integrated tracking system. A failure detection algorithm with the use of a fuzzy inference was implemented in the fusion algorithm to evaluate the confidence degree of external measurement signals.

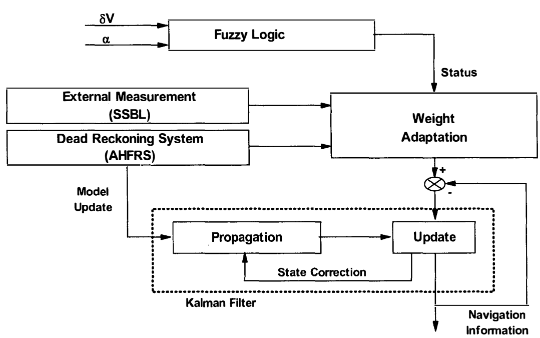

Figure 5. Schematic diagram of the hybrid navigation system

The tendency of the sensor failure can be decided with the aids of the fuzzy inference. Because the behavior of the underwater vehicle changes slowly as mentioned in previous section, it is reasonable to predict the motion of the vehicle with the signal from the AHFRS when failure occurs. As shown in Figure 5, each position data set of AHFRS system and SSBL system are summed with weighting factors, in which the weighting factor is calculated from the fuzzy logic corresponding to the tendency of failure. As the level of failure increases, the fuzzy logic decides that the confidence of the external measurements goes down and decreases the weighting factor of the SSBL system. The proposed failure detection and Kalman filter algorithm detects the failure in real-time and estimates the states stable whether the external measurements are fail or not.

Obstacle Avoidance Sonar System

VORAM has five range sonar sensors for obstacle avoidance and one altimeter for detecting altitude in front of the vehicle. The altitude sonar and range sonar are programmable, of which ranges are from 20m to 200m. Their operating frequencies are 50 kHz and 73 kHz, respectively. Figure 6 shows the schematic diagram of the obstacle avoidance sonar system. One signal processing unit manages range sonar sensors up to eight channels to minimize room in the sensor package. The OAS system can automatically regulate the range when the detected range is over the given range (KRISO report, 1997).

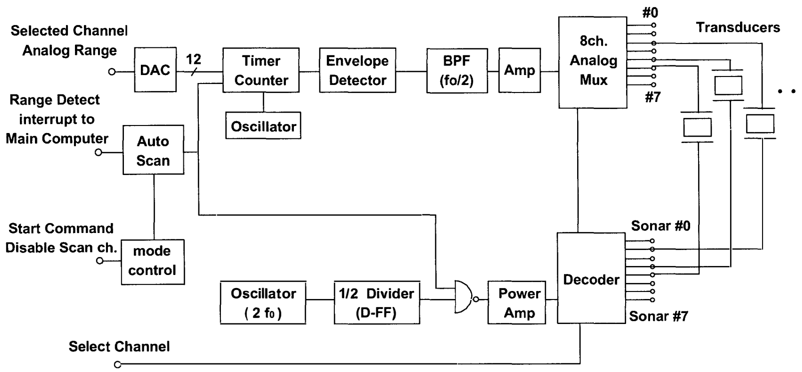

Figure 6. Block diagram of obstacle avoidance sonar(OAS) system

An obstacle avoidance algorithm is designed to detect the slant angle of bottom floor and to smooth the estimated curve of bottom floor. A simulation of obstacle avoidance with the OAS system is depicted in Figure 7, which is performed with full nonlinear dynamics and discrete-time sliding mode controller. The target depth is 3 meter in vertical with constant forward propulsion. In this figure, dotted line is the estimated target depth and solid line is the depth of the vehicle. When the height of the obstacle is greater than the maximum slant of the vehicle, the controller reduces forward speed and makes a detour around the obstacle.

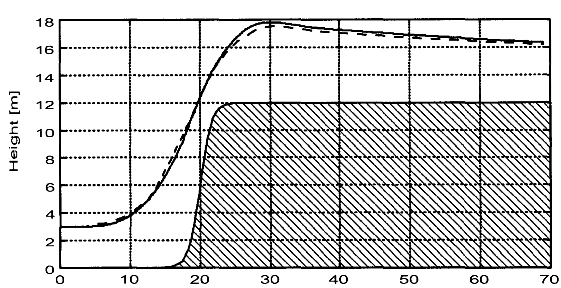

Figure 7. Simulation of obstacle avoidance with OAS system

UNDERWATER IMAGE COMMUNICATION SYSTEM

A unidirectional underwater image communication system is being developed in KRISO for real-time monitoring of seabed (Lim et al., 1997, KRISO report, 1997). The image communication system is designed on the basis of $\pi/4$ QPSK (Quadrature Phase Shift Keying) modulation method in order to maximize the performance of transmission rate. A signal train is adopted at initial stage to syncronize the image data. Center frequency and bandwidth of the acoustic transducer is 129 kHz and 12 kHz, respectively.

Figure 8 shows the block diagram of the system. Image data is modulated with a QPSK modulator that is composed of PLL and counter circuit. After a frequency modulation (FM), the system modulates the signal to match with the transducer, and amplified signal is transmitted. In receiver circuit, a 5-step limiter eliminates the component of amplitude modulation (AM) in the received signal. Image reconstruction is performed after QPSK demodulation. Communication speed of the system is 9600 bps in calm sea at present, which will be able to be increased. An adaptive equalizer is being designed with a Normalized Least Mean Square (NLMS) algorithm.

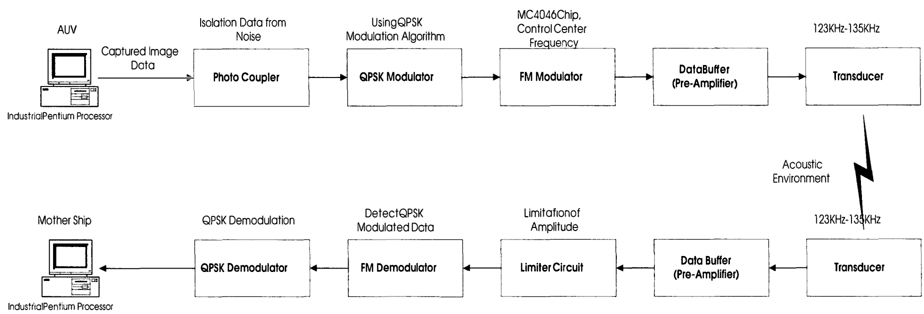

Figure 8. Block diagram of an underwater image communication system

ROBUST DIGITAL CONTROL

Sliding mode controller has been successfully applied to underwater vehicle (Yoerger and Slotine, 1985, Cristi et al., 1990). For bottom following control of AUV, sample intervals exist to obtain obstacle information and its altitude using sonar. In addition, an active imaging device such as a forward looking sonar is essential to increase the autonomy of the underwater robotic vehicles. This device requires several seconds to make one image because of the transmission and reflection time of acoustic waves for each scanning direction and consequently produces an image every discrete time interval. Furthermore, in the case of VORAM AUV, control commands from a supporting ship remotely operate vehicle with the use of an acoustic telemetry modem or RF modem. Information of the position and motion of the vehicle is gathered by an SSBL tracking system and a motion reference unit. In discrete time implementation, as the sampling interval becomes large, a controller designed on the basis of continuous system can lead the system to chattering along the desired sliding mode and even to instability. A discrete-time sliding mode controller, therefore, is adopted to guarantee the robustness of control system with parameter uncertainties and a long sampling interval (KRISO report, 1997, Lee and Oh, 1998, Lee et al., 1998).

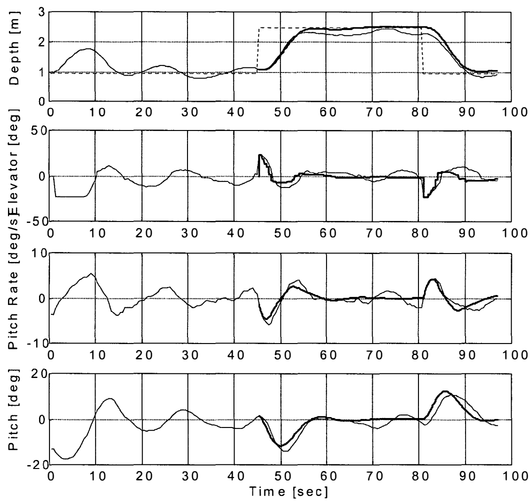

Figure 9. Depth keeping control with discrete-time quasi-sliding mode control: thin line - experiment, thick line - simulation

Figure 9 shows a depth keeping results of discrete-time quasi-sliding mode control when time interval is 0.5 seconds. Data communications were carried out every discrete time interval through RF modem at 1200 bps. Data receiving task was installed after test-run to transmit the control command and AUV motion data. The angle of elevator was designed being saturated to 0.4 radians. Dash line represents the desired depth, thin solid lines are experimental data, and thick solid lines show simulation results where initial data is same with the experimental data. The experimental results in general agree with the simulation results. In this figure, the initial oscillation was caused by transient response that was generated by manual control. It is hard to maneuver the AUV with manual control near the free surface because of large inertia and nonlinear hydrodynamic characteristics. In case of depth change, transient response shows good agreement between experiments and calculations.

CONCLUSION

This paper describes the configuration of VORAM AUV, which is designed to be remotely controlled at surface vessel with acoustic link and to be able to maneuver with pre-programmed mission. VORAM is equipped with a hybrid navigation system composed of a SSBL and a motion reference unit, an acoustic telemetry modem, an acoustic image communication system, obstacle avoidance sonar, an altitude sonar. A robust digital controller, discrete-time sliding mode control, is adopted to make the AUV stable under system uncertainties and external disturbances.

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STORM SURGES AND INUNDATION ON THE ANDHRA COAST, INDIA

S.K. Dube[1], P. Chittibabu[1], P.C. Sinha[1], A.D. Rao[1], T.S. Murty[2] and Y.R. Rao[3]

[1]Indian Institute of Technology, Hauz Khas
New Delhi, INDIA

[2]W.F. Baird & Associates Coastal Engineers
Ottawa, CANADA

[3]National Institute of Ocean Technology, IIT Campus
Chennai, INDIA

ABSTRACT

The State of Andhra Pradesh lies in the southern part of India and borders on the Bay of Bengal. It is subjected once every few years to inundation and flooding from storm surges, mainly in the deltas of the two major rivers in the state, namely Godavari and Krishna. This short paper documents some of the observed data and some results from numerical model simulations. These results will hopefully assist in developing a mitigation plan for surges, as well as for long range planning of coastal development.

INTRODUCTION

Andhra Pradesh (AP) has a coastline of length in excess of one thousand kilometers along the Bay of Bengal. Storm surge occurrence in the Bay of Bengal has a bimodal distribution annually, i.e. they occur at two different periods in the year. The bimodal distribution is related to apparent movement of the sun with reference to the earth's equator. Because of this apparent motion the sun, the intertropical convergence zone (ITCZ) migrates north and south of the equator (Figure 1).

Storm surges predominantly occur either during the pre monsoon season (April - May) or the post monsoon season (October to December). Tropical cyclogenesis occurs in the Andaman sea during these periods, mainly due to a combination of the following three factors: temperature in the upper layers of the ocean exceeding 27 (C, a weak wind shear and Coriolis parameter that is higher than zero. On occasion, remnants of pacific typhoons enter the Andaman Sea and get rejuvenated.

In keeping with the general circulation of the atmosphere, initially the tropical cyclones travel from east to west and make a landfall either on the Tamilnadu (TN) coast or the AP coast of India. More often they recurve and strike the coasts of Orissa, West Bengal and Bangladesh. In the case of extreme recurvature, they strike the coast of Myanamar.

The total water level envelop is made up of the storm surge, the tide, the wind wave setup and the interaction between the storm surge and the tide. On the coast of AP, the range of the tide varies from 1 to 1.5 m (Figure 2). In addition, numerous estuaries and rivers puncture the coastline. The tides and surges penetrate these rivers and propagate upstream. The increased flow in the rivers cause over-bank flooding (Figures 3 and 4).

A historical database of some forty-five storm surge events on the AP coast have been documented. This provides a useful input for the calibration and validation of numerical models so that better storm surge prediction and warning systems can be developed.

The following publications provide some information on storm surges on the AP coast: Dube et al (1997), Henry and Murty (1982), Henry et al (1998), Johns et al (1981, 1983, 1985), Kowalik and Murty (1993), Murty (1982), Murty and Henry (1983), Murty (1984), Murty et al (1986), and Rao et al (1997).

DISCUSSION OF OBSERVATIONS AND MODEL SIMULATIONS

Table 1 lists the important surge events for the AP coast. For lack of space instead of showing all the forty-five events, only the significant cases are listed. Table 2 provides a comparison of the numerically simulated results with observations for a few cases. As can be seen there is reasonable agreement. Table 3 lists the extent of inland penetration of storm surges on the AP coast for the regions shown in Figure 5.

Table 1. Severe cyclonic storms having potential of producing significant surges along the Andhra coast during 1891 to 1996.

No.	Cyclone	ΔP (mb)	R (km)	Land Lat (n)	Maximum Wind Speed (Knots)
1	1895 Kakinada	35	18	17.2	70
2	1906 Vizag	25	15	17.9	60
3	1921 Nellore	30	15	14.3	60
4	1925 Machili	60	20	16.1	108
5	1927 Nellore	80	25	14.3	100
6	1940 SH	30	22	14.0	60
7	1945 Machili	50	19	16.3	90
8	1949 Machili	60	25	16.3	110
9	1965 Vizag	30	15	17.9	62
10	1969 Kakinada	45	25	16.7	96
11	1972 SH	30	15	13.8	80
12	1976 Machili	30	15	16.1	70
13	1976 Kavali	28	15	14.8	60
14	1977 Divi	80	40	15.8	135
15	1977 Kavali	26	15	14.8	55
16	1979 Kavali	60	35	14.8	100
17	1984 SH	60	25	14.0	102
18	1987 Nellore	26	15	14.4	50
19	1987 Machili	26	15	15.9	50
20	1989 Kavali	70	20	14.8	110
21	1990 Divi	80	40	15.7	136
22	1994 Madras	30	25	13.0	75
23	1996 Kakinada	35	20	16.7	90

ΔP: Pressure Deficit, R: Radius of Maximum Winds

Table 2. Comparison of Observed and Computed Surges on the AP Coast

	Surge (m)		Location of Peak	
Cyclone	Observed/ Reported	Computed	Observed	Computed
1927 Nellore	3.0	3.1	North of Nellore	Nellore
1949 Machili	2.5	2.1	Machilipatnam	10 km N of Machilipatnam
1969 Kakinada	2.6	2.8	Kakinada	Kakinada
1977 Divi	5.0	4.9	Divi	Divi
1979 Kavali	3.0	3.3	Kavali	10 km North of Kavali
1989 Kavali	3 to 4	3.8	40 km N Kavali	48 km N Kavali
1990 Divi	4.5	4.4	Divi	Divi
1996 Kakinada	1.5	1.6	Kakinada	Kakinada

Table 3. Inland Penetration of Storm Surges on the AP Coast
(with reference to the zones shown in Figure 5)

Zone	Surge (m)	Slope	Inundation (km)
A	0.5	.0025	Nil
B	.83	.0025	.05
C	1.3	.002	3.0
D	1.4	.002	3.1
E	3.15	.002	4.8
F	3.07	.002	6.6
G	3.85	.0017	5.8
H	4.95	.0015	8.5
I	1.8	.002	3.0
J	2.82	.002	3.6
K	1.05	.0027	2.3
L	0.8	.0025	0.6

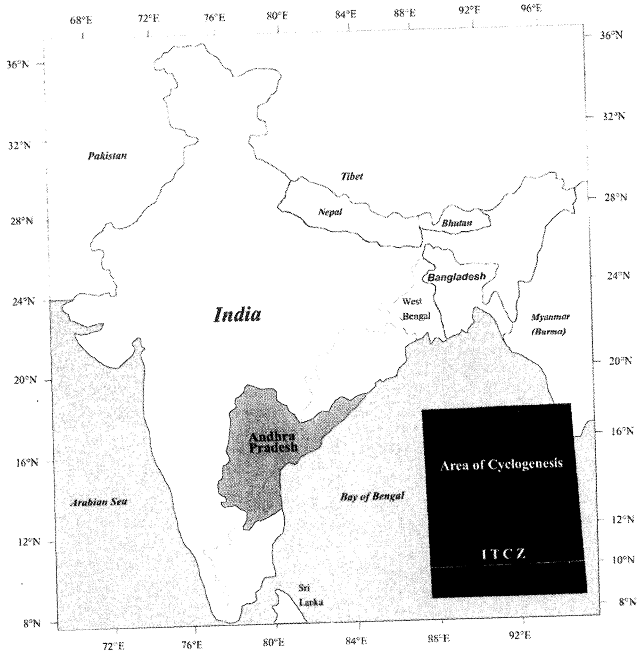
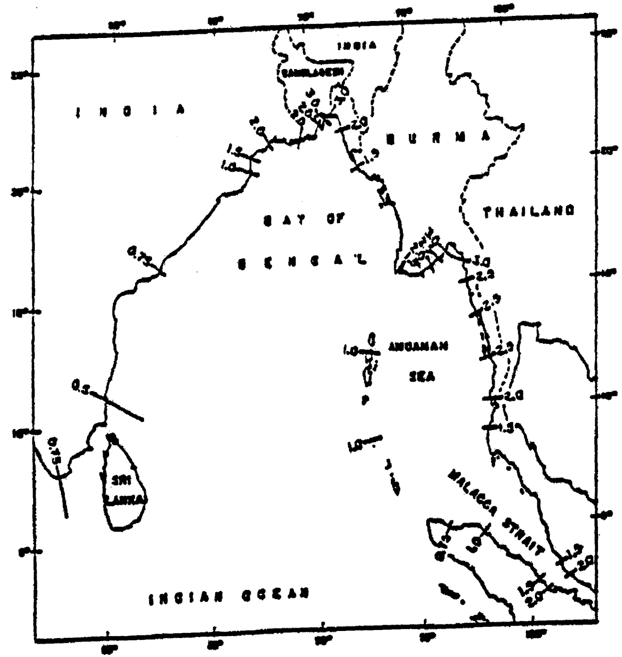


Figure 1. Area of Cyclonegenesis



Half –range of tide (approximated by $M_2 + S_2 + K_1 + O_1$)

Figure 2. Half Range of Tide (m)
In the Bay of Bengal

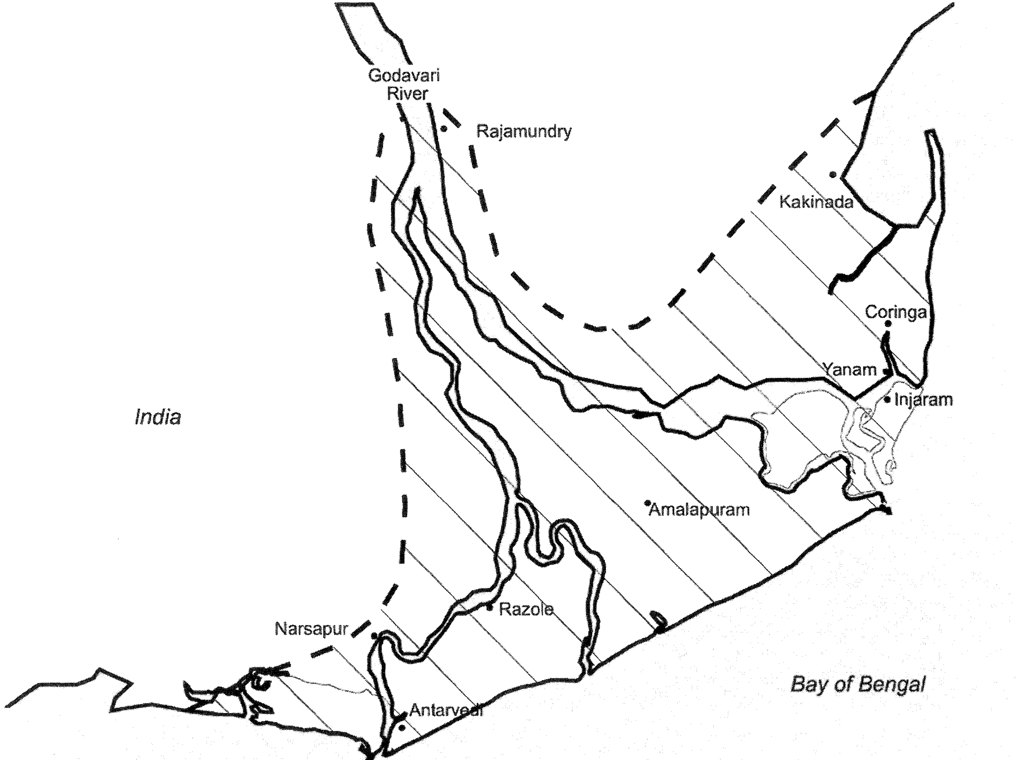


Figure 3. Composite Flood Map for the Godavari River

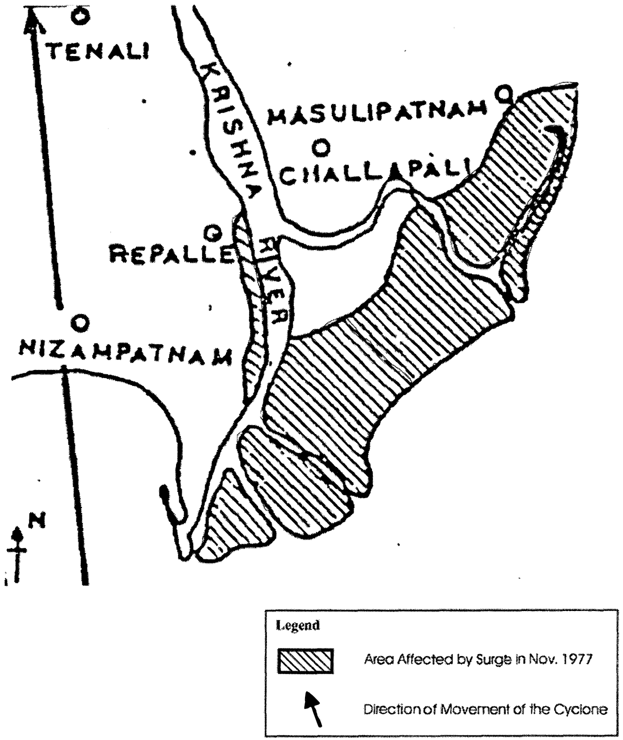


Figure 4. Cyclone Flood Map for the Krishna River (From I.M.D.)

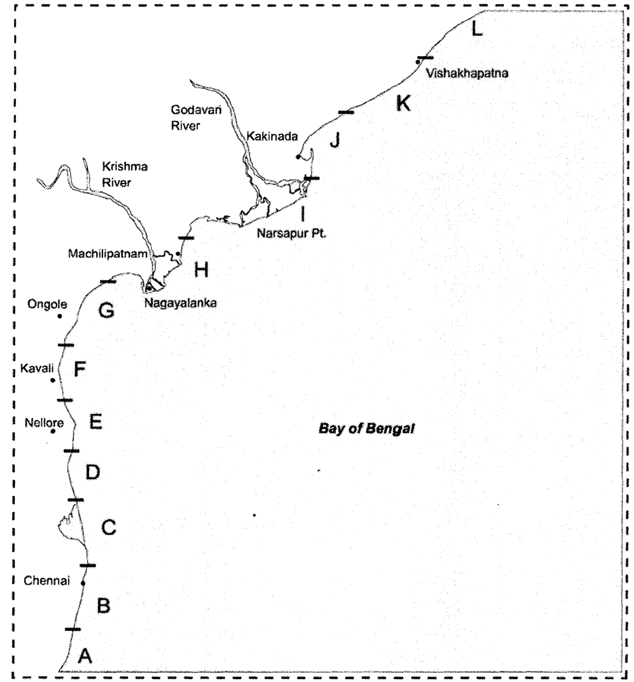


Figure 5. Division of Par of East Coast of India into 12 Segments Based on Storm Surge Penetration Inland

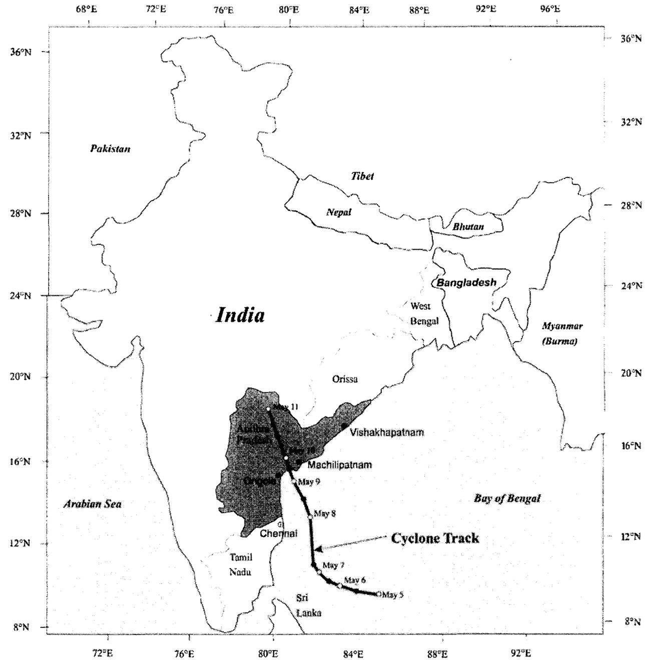


Figure 6. Cyclone Track of May 1990

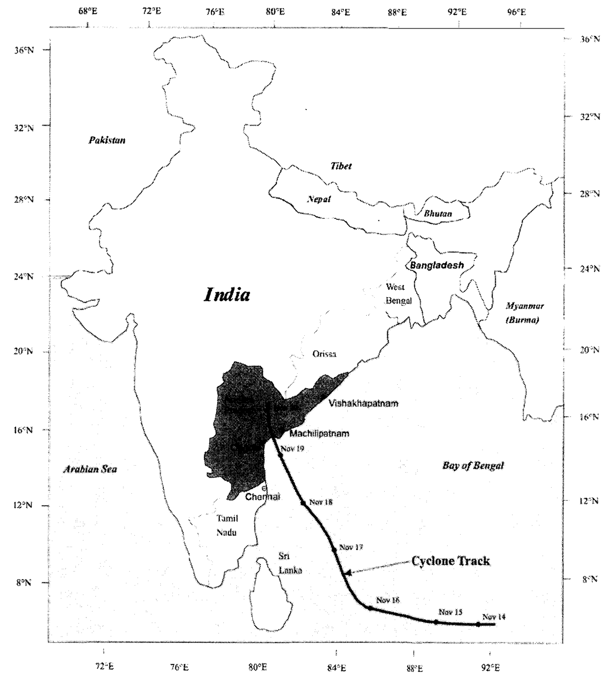


Figure 7. Cyclone Track of November 1977

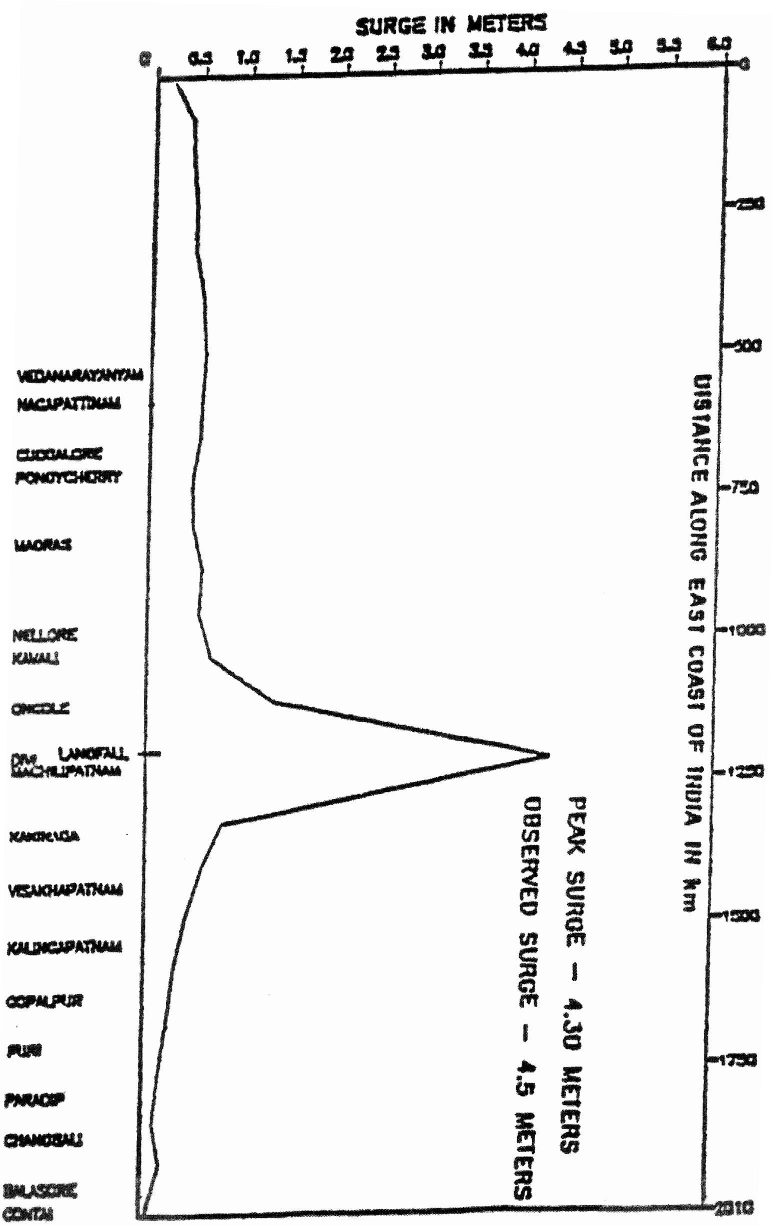


Figure 8. Peak Surge Envelope Associated with the May 1990 Cyclone

Figure 6 shows the track of the May 1990 cyclone that is among the top in terms of damage and deaths on the AP coast in the 1990's. Figure 7 shows the track of the November 1977 cyclone that caused over 10,000 deaths. Figure 8 shows the surge envelop for the 1990 cyclone along the east coast of India as simulated by our numerical models. Even though no tide gauge data are available for comparison, the results are in reasonable agreement with published descriptive information. The surge envelop for this event is similar to that for the May 1990 cyclone, considering the fact that the point of landfall is almost the same for both events. The results presented here are from finite-difference models including inundation simulations. We also have access to various finite-element models with irregular triangular grids.

We have also studied the effects of sea level rise and El-Nino events on storm surges on the AP coast. Lack of space would not permit any discussion of these results here.

SUMMARY

The State of Andhra Pradesh in India has a coastline of more than 1000 km along the Bay of Bengal. Once every few years a storm surge would cause loss of life and enormous destruction. The results based on observation as well as simulations from numerical models are briefly presented. The surges penetrate the estuaries of the two most important rivers in the state, namely Godavari and Krishna and can cause extensive flooding of these river deltas.

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POPULATION DYNAMICS AND STOCK ASSESSMENT OF SHARP-TOOTHED EEL, *MURAENESOX CINEREUS*, IN KOREAN WATERS

Chang Ik Zhang, Yong-Joo Kang, Cha-Soo Park[1] and Myoung Ho Sohn[1]

Pukyong National University
Pusan 608-737, KOREA
cizhang@dolphin.pknu.ac.kr

[1]National Fisheries Research and Development Institute
Pusan 626-900, KOREA

ABSTRACT

Population parameters and stock biomass of the sharp-toothed eel, *Muraenesox cinereus* in Korean waters were estimated and optimum fishing strategies were developed, based on biological samples and fishery data. The von Bertalanffy growth parameters estimated from a nonlinear regression were L_∞=162.80 cm, K=0.1640, t_0= -0.2091. The survival rate (S) was estimated to be 0.567, and the instantaneous coefficient of natural mortality (M), 0.313/yr. From the values of S and M, the instantaneous coefficient of fishing mortality (F) for recent years was calculated to be 0.255/yr. The age at first capture was 1.7 years. Based on these parameters, the annual biomass of the stock was estimated from a biomass-based cohort analysis using times series of catch at age. The biomass peaked in 1977 at about 65,000 tonnes. However, it then declined continuously to a level of 7,000 tonnes in 1995. The maximum sustainable yields (MSY) from the Schaefer and Fox production models were estimated to be about 7,100 and 6,600 tonnes, respectively. A yield-per-recruit analysis showed that the current yield-per-recruit of about 290 g with F=0.255/yr, where the age at first capture (t_c) is 1.7 years, was lower than the maximum possible yield per recruit of 355 g. Fixing t_c at the current level and increasing fishing intensity (F) yielded a decrease in the yield per recruit from 290 g to about 180 g. However, the estimated yield per recruit increased to 325 g by increasing t_c from the current age (1.7 years) to age 4 with F fixed at the current level. Age 4 corresponds to the optimal length at first capture obtained from the $F_{0.1}$ method. Yield-per-recruit and spawning biomass per recruit were estimated under various harvest strategies based on F_{max}, $F_{0.1}$, $F_{35\%}$ and $F_{40\%}$.

Key words : biomass, cohort analysis, recruitment, production model,
maximum sustainable yield, $F_{0.1}$, $F_{35\%}$, $F_{40\%}$

INTRODUCTION

The sharp-toothed eel *Muraenesox cinereus* has been traditionally one of the most valuable fisheries resources in Korean waters. This species is widely distributed and caught in the western and southern seas of Korea, the East China Sea and the southern sea of Japan (Figure 1, Chyung, 1977). The spawning season of this species ranges from April to July with a peak in June, when water temperatures reach about 20° (National Fisheries Research and Development Institute (NFRDI), 1988).

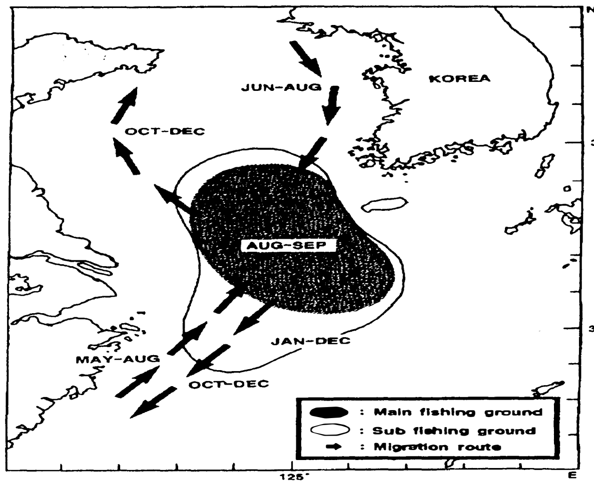

Figure 1. The main distribution area, fishing ground and migration route of sharp-toothed eel in the Yellow Sea and the East China Sea (Adopted from Park et al., 1998).

In Korea, this species is usually caught by large bottom trawls, stow nets, longlines and traps, of which about 50% of the total is taken by the large bottom trawl fishery. Annual catches of sharp-toothed eel have drastically declined since 1978. Annual catches reached their highest level at 10,000 tonnes in 1978, declining to their lowest level of 1,600 tonnes in 1995 (Table 1).

Table 1. Annual catches of sharp-toothed eel by fishing gear in Korean waters (Data from NFRDI, 1998)

(Unit : MT)

Year	Large bottom trawls	Stow nets	Longlines	Traps	Others	Total
1976	2,390	1,103	1,060	628	980	6,161
1977	3,364	1,717	870	826	1,981	8,758
1978	3,145	1,324	518	1,870	2,995	9,852
1979	2,482	1,145	348	890	1,363	6,228
1980	2,843	831	262	451	902	5,289
1981	3,322	1,451	234	879	828	6,714
1982	5,250	2,261	444	540	684	9,179
1983	5,359	1,508	247	366	566	8,046
1984	6,269	1,105	232	320	479	8,405
1985	2,794	918	177	624	882	5,395
1986	2,600	1,224	475	237	504	5,040
1987	2,420	2,343	224	156	448	5,591
1988	2,185	967	338	388	331	4,209
1989	1,078	549	200	836	419	3,082
1990	1,148	320	186	408	640	2,702
1991	636	921	263	466	806	3,092
1992	1,077	536	132	368	503	2,616
1993	1,242	1,081	223	518	696	3,760
1994	648	283	478	206	628	2,243
1995	311	363	274	257	399	1,604

Despite the importance of the sharp-toothed eel fishery and the apparent critical condition of the stock, relevant scientific knowledge concerning population dynamics and stock assessment is virtually non-existant, which has made it difficult to develop a reasonable management policy. Thus far, there has not been enough essential research on the biological characteristics, stock assessment and management of this species. Some reports available describe its general ecology, fishing grounds and stock conditions (NFRDI, 1988; 1994). Recently, Kang et al. (1998a) carried out a study on the maturity and spawning of this species. Kang et al. (1998b) also studied its age and growth. For optimal management of this stock, it is necessary to have accurate information on the population parameters, biomass, optimal levels of catch and fishing effort, and age at first capture. The purpose of this research is to estimate these parameters and determine the status of this resource.

In this paper we estimate annual biomasses and assess the current state of the stock. The basic approach was to reconstruct historical population biomass and fishing mortality using life history parameters and age-structured catch data. These results were then applied to production models and the yield-per-recruit analysis.

MATERIALS AND METHODS

Growth parameters

Although there are many methods for estimating von Bertalanffy growth parameters, we used a nonlinear regression method because it had the smallest sum of squares (SSQ) (Zhang, 1996). The initial values of von Bertalanffy growth parameters applied in this paper were L_∞=164.54 cm, K=0.1629, t_0= -0.2193 which were obtained from Walford's (1946) method. Length at age data obtained from 555 otoliths collected from specimens between August, 1996 and December, 1997 were used as input data.

Survival rate (S) and growth rate (G)

In estimating survival rate, we used the average age composition data for 1993•1995 from the large bottom trawl fishery. These data were used to construct an average catch by age to produce a catch curve, calculate mean age and apply to the Chapman and Robson (1960) and Beverton and Holt (1957) methods as described by Zhang (1991).

We calculated the instantaneous coefficient of growth at age (G_j) by the following model equation.

$$G_j = \ln(\frac{W_{j+1}}{W_j}) \tag{1}$$

where, W_j and W_{j+1} are the body weights at age j and j+1, respectively.

As input data, we used von Bertalanffy growth parameters that were obtained above and length-weight relationship from Kang et al. (1998b).

Instantaneous coefficients of natural and fishing mortality

The instantaneous coefficient of natural mortality was determined as a mean of the estimates by the Alverson and Carney (1975) and Alagaraja (1984) methods using von Bertalanffy growth parameters, a maximum age (t_m) of 15 and age at maximum biomass of 5.7 (NFRDI, 1988). The instantaneous coefficient of fishing mortality (F) was estimated as the instantaneous coefficient of total mortality (Z) less the instantaneous coefficient of natural mortality (M), and the Z was transformed from the survival rate as $S=e^{-Z}$.

Age at first capture (t_c)

Generally, age at first capture of a stock is estimated from fishing experiments using various sizes of cod-end mesh. Since this information was not available, we used the Pauly (1984) method which is based on a length-converted catch curve. We also used length composition data collected from the large bottom trawl fishery from 1996 to 1997 to estimate the recent age at first capture.

Biomass and instantaneous coefficient of fishing mortality

We adopted the biomass-based cohort analysis (Zhang, 1987; Zhang and Sullivan, 1988) for analyzing biomass and instantaneous fishing mortality at age and by year according to the following model equations :

$$B_{ij} = B_{i+1,j+1}e^{(M-G_j)} + C_{ij}e^{\frac{(M-G_j)}{2}} \quad (2)$$

$$F_{ij} = \ln(\frac{B_{ij}}{B_{i+1,j+1}}) - M + G_j \quad (3)$$

where, C_{ij} and $C_{i+1,j+1}$ are catches in weight at age j and j+1 in year i and i+1, B_{ij} and $B_{i+1,j+1}$ are biomass at age j and j+1 in year i and i+1, F_{ij} is the instantaneous coefficient of fishing mortality at age j in year i, M is instantaneous coefficient of natural mortality and G_j is instantaneous coefficient of growth at age j.

As input data for the biomass-based cohort analysis model, we used catch in weight at age for the years of 1976•1995, an instantaneous coefficient of growth at age, an instantaneous coefficient of natural mortality and terminal fishing mortality.

Maximum sustainable yield (MSY) and F_{MSY}

We employed the Schaefer (1954) and Fox (1970) production models, which assumed logistic and Gompertz population growth, respectively. The model equations are :

$$Y^* = U_\infty f - [\frac{U_\infty q}{r}]f^2 \quad (4)$$

$$Y^* = U_\infty \exp(-\frac{qf}{r})f \quad (5)$$

where, Y* is equilibrium yield, U_∞ is asymptotic CPUE, q is the catchability coefficient, r is the intrinsic natural growth rate and f is fishing effort.

As input data for the Schaefer (1954) and Fox (1970) models to determine MSY and f_{MSY}, we used total catches and CPUE data from the Korean large bottom trawl fishery during 1976-1995. We estimated the annual index of total fishing effort by dividing total catch by CPUE value.

Optimal fishing mortality and age at first capture

Yield-per-recruit analysis

We analyzed yield-per-recruit of sharp-toothed eel by the model of Beverton and Holt (1957) to estimate the optimal fishing mortality and the optimal age at first capture. The model equation is expressed as :

$$\frac{Y}{R} = Fe^{-M(t_c - t_r)} W_\infty \sum_{n=0}^{3} \frac{U_n e^{-nK(t_c - t_0)}}{F + M + nK} (1 - e^{-(F+M+nK)(t_m - t_c)}) \quad (6)$$

where, asymptotic weight (W_∞) of 7,810 g, growth coefficient (K) of 0.164/yr and age at zero length (t_0) of -0.2091/yr are parameters of von Bertalanffy growth function; R is the number of fish alive at time $t=t_r$ of 0.9, the age at recruitment; Y is yield; F and M are instantaneous coefficients of fishing and natural mortality of 0.255/yr and 0.313/yr, respectively; t_c is the age at first capture of 1.7 years; t_m is the maximum age in the catch of 15 years (NFRDI, 1988); and U_n is a summation parameter equal to +1, –3, +3, and –1 for n = 0, 1, 2 and 3, respectively.

Optimal $F_{0.1}$ method

$F_{0.1}$ represents the fishing mortality corresponding to 10% of the slope at the origin which indicates no fishing. In this paper, we used the following equation after differentiating the Beverton and Holt (1957) model to estimate the $F_{0.1}$ value which corresponded to 10% of the equation.

$$\left[\frac{d(Y/R)}{dF}\right]_{F=0} = e^{-M(t_c - t_r)} W_\infty \{\frac{1}{M} - \frac{3e^{-K(t_c - t_0)}}{M + K} + \frac{3e^{-2K(t_c - t_0)}}{M + 2K} - \frac{e^{-3K(t_c - t_0)}}{M + 3K}\} \quad (7)$$

As input data, we used M, K, t_c and t_0 from earlier estimates.

Spawning biomass-per-recruit model

Using the spawning biomass per recruit model equation below, we estimated instantaneous coefficients of fishing mortality which maintained the spawning biomass at 35% ($F_{35\%}$) and 40% ($F_{40\%}$) at a given age of recruitment for an unfished population. Generally, it is known that $F_{35\%}$ is preferable because it maintains the proper level of spawning biomass per recruit for any combination of maturity and recruitment schedule. The model equation is expressed as :

$$\frac{SB}{R} = m_t e^{-M(t_c - t_r)} W_\infty \sum_{n=0}^{3} \frac{U_n e^{-nK(t_c - t_0)}}{F + M + nK} (1 - e^{-(F+M+nK)(t_m - t_c)}) \quad (8)$$

where, SB is spawning biomass and m_i is maturity rate at age. The maturities at age were 0.05, 0.25, 0.5, 0.75 and 1.0 for ages 1, 2, 3, 4, and 5, respectively and age 5 was considered to be the age at full maturity (Kang et al., 1998a).

RESULTS

Population parameters

We obtained von Bertalanffy growth parameters for sharp-toothed eel using the Solver program of MS EXCEL. These esimates of L_∞=162.80 cm, K=0.1640 and t_0= -0.2091 were a little different from the initial values obtained from Walford's plot (Table 2). The growth curve for this species is shown in Figure 2.

Table 2. Comparison of von Bertalanffy parameters of the sharp-toothed eel in Korean waters estimated from the Walford graph method (initial value) and the EXCEL-Solver nonlinear regression method

	Parameters			
	L_∞	K	t_0	SSQ
Initial value	164.54	0.1629	-0.2193	34.4978
Estimated value	162.80	0.1640	-0.2091	22.0713

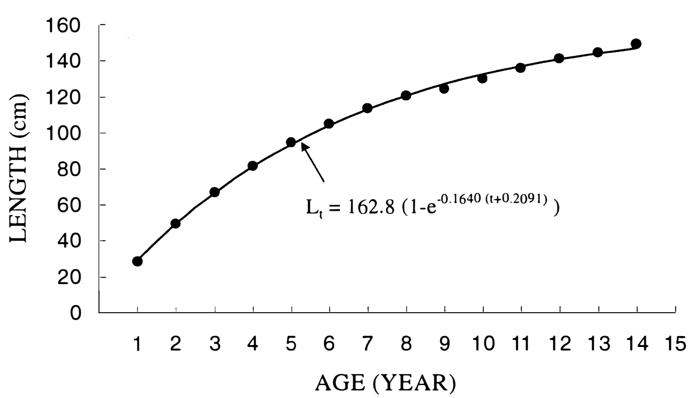

Figure 2. The von Bertalanffy growth curve of the sharp-toothed eel in Korean waters estimated from the nonlinear regression method.

Estimates of survival rate ranged from 0.4658 to 0.5847 based on four different methods (Table 3). Among these methods, the catch curve produced the highest value and the Beverton and Holt's (1957) had the lowest value. The catch curve and Chapman and Robson (1960) methods provided variance estimates for the survival rates. We therefore chose the survival rate of 0.5669 obtained from the Chapman and Robson (1960) method, which had the lower variance of the two methods. We estimated the instantaneous coefficient of natural mortality from the Alverson and Carney (1975) and Alagaraja (1984) methods as 0.318/yr and 0.307/yr, respectively (Table 4).

Table 3. Estimates of survival rates of sharp-toothed eel in Korean waters, using mean age composition for three years by four different methods

Methods	S	Z	Var(S)
Catch curve	0.5847	0.5366	0.000375
Mean Age	0.5669	0.5676	NA
Chapman and Robson	0.5669	0.5676	0.000000519
Beverton and Holt	0.4658	0.7640	NA

Table 4. Estimated instantaneous coefficient of natural mortality (M) of the sharp-toothed eel derived by two methods and the input data for these methods

Methods	Estimated M	Input data
Alverson and Carney	0.318	K=0.1640/year t_{mb}=5.7 year
Alagaraja	0.307	t_m=15 year
Average	0.313	

We selected the mean value from the two methods (0.313/yr) as the best estimate of the instantaneous coefficient of natural mortality. The recent instantaneous coefficient of fishing mortality was 0.255/yr by subtracting the instantaneous coefficient of natural mortality (0.313/yr) from the instantaneous coefficient of total mortality (0.568/yr) which was transformed from the survival rate ($S=e^{-Z}$) by the Chapman and Robson (1960) method.

Figure 3 shows annual changes in the instantaneous coefficient of fishing mortality (F) for 1976~1995. The F estimates were generally higher in 1986~1995 (CV=20.1%) than in 1976~1985 (CV=26.6%). Based on results from a t-test, mean fishing mortalities in the two periods (that is, $H_0 : H_{76\text{-}85}=H_{86\text{-}95}$) showed significant differences (P<0.01). The age at first capture (t_c) was determined to be age 1.7 based on the Pauly (1984) method and using length composition data from Kang et al. (1998b).

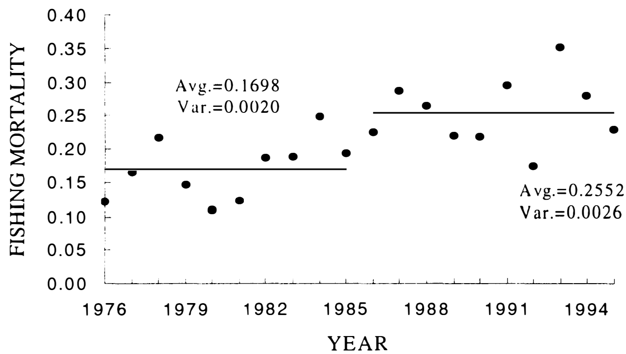

Figure 3. Annual changes in fishing mortality of sharp-toothed eel in Korean waters.

Annual biomass and MSY

The estimates of total annual biomass showed a peak in 1977 at 65,000 tonnes, followed by a decline to 7,000 tonnes in 1995. The annual CPUE estimates showed a peak in 1982 at 28kg/haul and then a decline to 2kg/haul in 1995, similar to the trend in biomass except for differences during 1976~1982 (Figure 4).

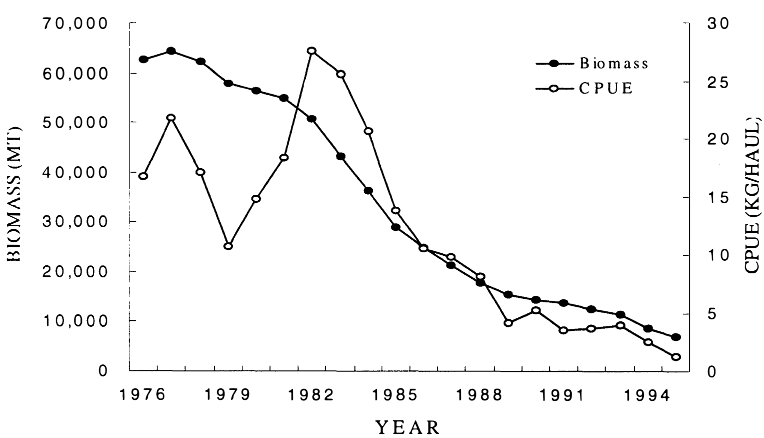

Figure 4. Annual changes in total biomass and CPUE of sharp-toothed eel in Korean waters, 1976-1995.

The values of MSY estimated by the Schaefer (1954) and Fox (1970) production models were similar at 6,620 and 7,057 tonnes, respectively. The fishing intensity needed to achieve MSY was somewhat different between the two models at 310,500 and 517,700 hauls (Figure 5).

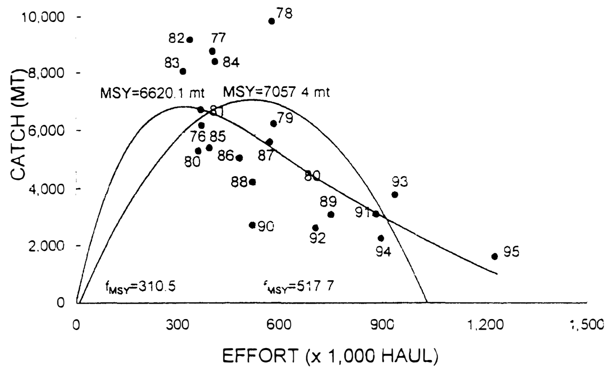

Figure 5. Equilibrium yield curves for sharp-toothed eel in Korean waters from the Schaefer (1954) and Fox (1970) models.

The relationship between biomass and recruitment

To determine the relationship between recruitment and biomass, we analyzed the annual biomass at age data estimated from the biomass-based cohort analysis. Recruitment was considered as the biomass at age 2 since the t_c estimate was age 1.7. Recruitment showed a continuously declining trend from the mid-1970's, which was similiar to the trend in biomass. The relationship between recruitment and biomass showed a rather linear pattern (R^2=0.853), implying a density independent effect, which differs from results of the Ricker or Beverton and Holt (1957) curves that indicate a density dependence effect (Figure 6).

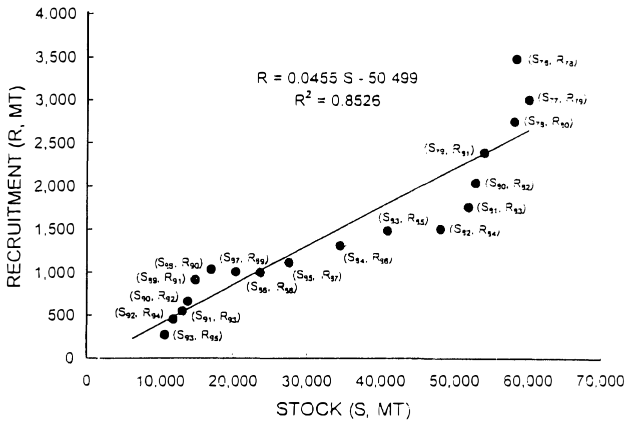

Figure 6. Relationship between stock and recruitment of sharp-toothed eel in Korean waters, 1976-1995.

Optimal fishing intensity and age at first capture

To examine changes in yield per recruit by changing the age at first capture and the fishing mortality, we constructed yield isopleths (Figure 7). In this figure, AA' represents the maximum yield per recruit line at a given t_c and BB' indicates the maximum yield per recruit line at a given F. The estimated current average yield per recruit (F=0.255/yr, t_c=1.7 years) was about 290 g per recruit, which indicates that the fishery is operating below the maximum yield per recruit of 355 g. Fixing t_c at the current level and increasing fishing mortality, resulted in a decrease in yield per recruit from 290 g to about 189 g. The maximum yield per recruit is reached when F is about 0.32/yr and t_c about age 4, which increases the yield per recruit from the current level of 290 g to 355 g.

Table 5 shows the $F_{0.1}$ and F_{max} values from age 2 to 8 estimated from the Beverton and Holt (1957) model. The yield-per-recruit was highest (F_{max}=417.4 g and $F_{0.1}$ =352.9 g) at t_c=5 years. The $F_{0.1}$ and F_{max} values gradually increased until age 8, and the yield-per-recruit corresponding to each F value also increased to age 5, but the yield-per-recruit gradually decreased after that age.

The spawning biomass-per-recruit gradually increased until age 5 but it showed a declining trend at older ages (Table 5).

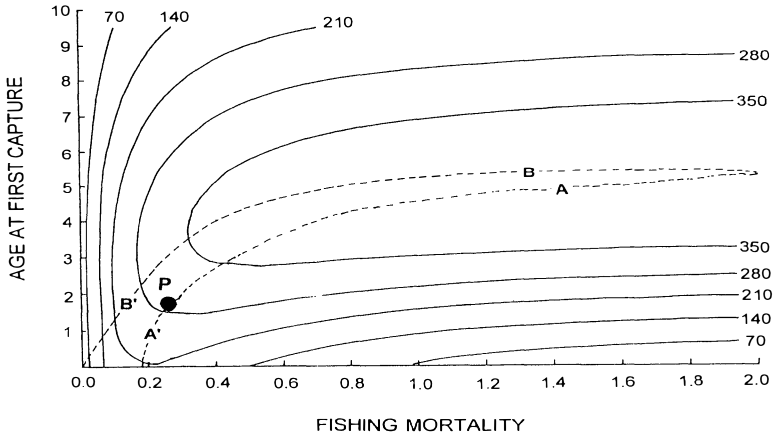

Figure 7. Yield isopleths for sharp-toothed eel in Korean waters. P represents the current state of fishing mortality (F) and age at first capture (t_c).

Table 5. Yield and spawning biomass per recruit at age 2 of sharp-toothed eel in Korean waters under harvest strategies on F_{max}, $F_{0.1}$, $F_{35\%}$ and $F_{40\%}$

Age at First Capture	F_{max}	$F_{0.1}$	$F_{35\%}$	$F_{40\%}$	Y/R (g) at		SB/R (g) at	
					F_{max}	$F_{0.1}$	$F_{35\%}$	$F_{40\%}$
2	0.36	0.2130	0.2469	0.2085	309.73	291.21	303.99	347.41
3	0.58	0.2664	0.2971	0.2489	360.83	329.85	569.36	650.69
4	1.08	0.3298	0.3489	0.2905	398.81	352.07	767.40	877.03
5	>2.00	0.3945	0.4009	0.3321	417.35	352.90	884.07	1010.37
6	>2.00	0.4557	0.4528	0.3741	404.96	334.36	737.14	842.45
7	>2.00	0.5138	0.5066	0.4180	369.43	302.55	594.91	679.89
8	>2.00	0.5278	0.5660	0.4669	322.11	264.27	465.40	531.89

The $F_{35\%}$ and $F_{40\%}$ values were 0.40/yr and 0.33/yr at age 5, respectively. For these F values, the highest spawning biomass per recruit at t_c=5 years was 884.07 g and 1,010.37 g. The $F_{35\%}$ and $F_{40\%}$ values also gradually increased until age 8, and the spawning biomass-per-recruit corresponding to these F values also increased until age 5, but then gradually decreased after that age. Yield-per-recruit and spawning biomass-per-recruit showed the same pattern at various F levels.

DISCUSSION

Although there are various models to derive growth parameters of fish species, we chose the von Bertalanffy growth model. These parameters were used as input data not only in estimating the age at first capture and the instantaneous coefficient of natural mortality but also in the yield per recruit model (Zhang, 1991).

In determining survival rate, in principle, we should use the age composition data which examined through whole life history of one cohort. But, generally, it's very difficult to get only about one cohort, we use sampled data for 1~2 years after assuming the equilibrium state of stock. In this study, we estimated the survival rate with age composition data of large bottom trawl catches during 1993-1995. And we selected the estimated survival rate as 0.567 derived from the Chapman and Robson (1960) method over those from other methods because it had the lowest variance.

Although the instantaneous coefficient of natural mortality is one of the most essential parameters used in almost all stock assessment and management models, it is not easy to determine accurately. Therefore, we employed the average value of 0.313/yr from the two most commom methods as an appropriate value of M, after that we also adopted F of 0.255/yr using the relationship between S and Z.

The CPUE from the commercial fishery for sharp-toothed eel have declined markedly from 18.6 kg/haul in 1976~1978 to 2.6 kg/haul in 1993~1995 (Figure 4). In this period, effort increased about 2.5 times from 448,000 hauls in 1976~1978 to 1,024,000 hauls in 1993~1995. In addition, total catches of the stock declined more than six-fold from 10,000 tonnes in 1978 to 1,600 tonnes in 1995. All of these evidences indicate a decline in stock abundance of sharp-toothed eel in Korean waters. Results from a biomass-based cohort analysis further suggest a remarkable decline in the stock. The estimated total biomass of the stock declined more than seven-fold from 63,000 tonnes in 1976~1978 to 9,000 tonnes in recent years.

As shown in Figure 3, fishing mortalities have generally increased and the mean fishing mortalities between the two decades of 1976~1985 and 1986~1995 showed highly significant differences ($P<0.01$). From these results, it is clearly evident that overfishing has occurred and that the decline in the stock was mainly caused by high fishing intensity. However, environmental factors, such as the devastation of spawning and nursery grounds by coastal water pollution and land reclamation and landfill projects, might also have contributed to the decline of the stock.

Maximum sustainable yield was estimated at about 6,600~7,000 tonnes from production models. The catch in 1995 was about 1,600 tonnes which indicates that the current catch is much lower than MSY. Although production models have some advantages in estimating MSY and F_{MSY} when only limited information is available such as time-series of catch and effort data, these models assume that the stock was in a steady state. Therefore, these models produce estimates with limited accuracy when fluctuations in biomass are caused by abnormal environmental factors.

According to the yield-per-recruit analysis, the current level of fishing intensity and age at first capture ($F=0.255$/yr, $t_c=1.7$ years) produced only 290 g per recruit. Increasing the age at first capture to age 4 at the current fishing intensity would produce a higher yield per recruit (about 325 g). However, the more fishing intensities increased, the more the yield per recruit decreased (Figure 7).

Therefore, the average fishing intensity of 0.29/yr in 1993~1995 should be reduced to 0.21/yr which corresponds to $F_{0.1}$ and $F_{40\%}$ levels. Further, the age at first capture should be increased from age 2 to age 5 to achieve the highest spawning biomass-per-recruit of 1,010 g at the $F_{40\%}$ level for rebuilding the adult biomass and maintaining it at a sustainable level (Table 5).

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EFFECTS OF REGIME SHIFTS ON FISH STOCKS IN KOREAN WATERS

Chang Ik Zhang, Jae Bong Lee, Suam Kim[1] and Jai Ho Oh[2]

Pukyong National University
Pusan, KOREA
cizhang@dolphin.pknu.ac.kr

[1] Korea Ocean Research and Development Institute
Seoul, KOREA

[2] Meteorological Research Institute
Seoul, KOREA

ABSTRACT

Under the assumption that sea surface temperature (SST) has increased in the Pacific and caused world-wide atmospheric circulation to change on the long-term scales, some changes in the marine ecosystem and fisheries resources were detected in Korean waters in 1976/77 and 1987/88. The atmospheric condition in the North Pacific has changed from high air pressure to warm and low pressure during winter seasons (November to March) since 1976. Simultaneously, mixed layer depth (MLD) has become greater and plankton abundance and fish production has changed. In Korean waters, precipitation showed a decadal scale climatic event from 1976 to 1988. The year 1976 was recorded as a year in which thermal front extended abnormally northward. Zooplankton biomass decreased after 1976 then increased after 1988. The species composition and catch amounts of commercial fisheries altered in Korean waters. For example, the catches of walleye pollock, sardine, corvenias and mackerel increased, and saury decreased, after 1976. Catches of mackerel, squid, herring and jack mackerel increased, while those of pollock and saury declined, since 1988. Also, the phenomenon of species replacement in the catches was observed between pollock and herring as well as among saury, sardine and mackerel.

INTRODUCTION

At the level of the whole ecosystem, climatic changes such as those in air temperature, air pressure, precipitation, etc., are connected with changes in marine ecosystem structure and dynamics, such as surface water temperature, mixed layer depth, biological productivity at several trophic levels, etc. In the North Pacific, the Aleutian Low Pressure System has strong links to the oceanography of the North Pacific (Namias, 1969) and the intensification of this pressure system which occurred from 1977-88 (Graham, 1994; Trenberth and Hurrell, 1994) brought about the changes in the mixed layer depth. This phenomenon increased phytoplankton production (Polovina *et al.*, 1995; Venrick *et al.*, 1987; Falowski *et al.*, 1992). Further, a climate change in the North Pacific has been linked to changes in production of fish and shellfish (Beamish and Bouillon, 1993; Brodeur and Ware, 1992), such as sablefish (McFarlane and Beamish, 1992), lobster and reef fishes (Polovina *et al.*, 1994), salmon

(Francis and Hare, 1994), and pelagic fish population (Baumgartner *et al.*, 1992; Kawasaki, 1993). The North Pacific regime shift began in the mid 1970s, reached its greatest intensity in the early 1980s, and declined to pre-1975 levels by the late 1980s.

In the North Sea, the climate-driven regime shift in the late 1980s caused major reorganizations of ecological relationships. Positive winter air pressure anomalies induced stronger westerly winds, resulting in increased advection of water. Many species of phytoplankton and zooplankton showed marked changes in abundance at about 1988 (Reid *et al.*, personal communication). These events coincided with a large increase in the catches of horse mackerel in the North Sea.

Thus, it is meaningful to address the question of whether this phenomenon may also have occurred in Korean waters and if so, how the global regime shifts affected marine fisheries resources in Korean waters. The objectives of this study are (1) to examine whether the climate regime shifts occurred in 1976/77 and 1987/88 in Korea, (2) to identify evidence that the regime shifts influenced marine ecosystem and the production of fisheries resources in Korean waters, and (3) to establish scientific hypotheses for each process from the regime shifts to the changes in the structure of fisheries resources.

DATA AND METHODS

We examined the precipitation time series which would be connected to the Pacific climate variability (Ropelewski and Halpert, 1987). The Standardized Precipitation Index (SPI) calculated from monthly precipitation data covering the period May 1953~Dec. 1997 was used to examine the timing and strength of drought at Ullungdo-Island (37.5°N, 131°E) area in eastern Korean waters (data from the Korea Meteorological Administration).

$$SPI_i = \frac{x_i - \bar{x}}{s} = \frac{x_i - \hat{\alpha}\hat{\beta}}{(\hat{\beta}\hat{\alpha})^{1/2}} \qquad i = 12 \text{ months} \qquad (1)$$

where x represents 12 month mean precipitation; α, β are constants calculated by iteration of the maximum likelihood approximation (Wilks, 1995).

Sea temperature has been measured along 22 oceanographic lines and at 175 fixed stations in Korean waters bimonthly since 1961 by the National Fisheries Research & Development Institute (NFRDI). Vertical temperature profile data were available from the Serial Oceanographic Data Service of the Korea Oceanographic Data Center (KODC). We used these profile data to calculate the depth of the upper isothermal layer as a proxy for the mixed layer depth as suggested by Polovina *et al.* (1994), and annual variations in this depth were compared to annual variations of phytoplankton and zooplankton during 1961-1990.

The transparency data from the NFRDI were used to calculate chlorophyll *a* concentration which was considered as ocean primary productivity from the empirical equation.

$$C = 157.3 Z_{sd}^{-1.99} \qquad (2)$$

where C denotes chlorophyll *a* concentration (mg m^{-3}) and Z_{sd} represents Secchi depth (m) (Park, 1996).

Annual estimates of mean biomass of zooplankton (including copepoda, chaetognatha, euphausia and amphipoda) in the East Sea from the NFRDI data base during the period 1961-1996 were compared to annual variations in phytoplankton abundance and mixed layer depth (MLD). These MLD data for the East Sea were available from Dr. Polovina, which were downloaded at the National Oceanic and Atmospheric Administration (NOAA), USA.

Annual catch from 1960 to 1996 and monthly catch from 1971 to 1996 of major fisheries resources in Korean waters were obtained from the Statistical Yearbook of Agriculture, Forestry and Fisheries (SYAFF) to examine coherent, large scale changes in patterns of species succession. In addition, annual catch data from Japan of four pelagic species and catches of walleye pollock from Japan, North Korea, and Russia from 1960 to 1990 were used to search for evidence of simultaneous temporal variations.

We employed Student's *t*-test to examine statistical differences in the time series of meteorological, oceanographic, and fisheries catch data for the periods of pre-1976, 1976-1987, and post-1987. Correlation analyses were also conducted for the time series trends in catch data.

RESULTS

The precipitation at Ullungdo-Island located in the East Sea showed a decadal climatic event which increased in the mid 1970s and declined by 1988 (Fig. 1). In 1976, the thermal front

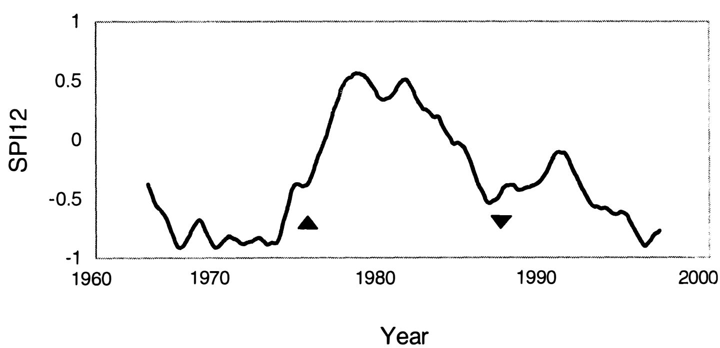

Figure 1. The 5-year moving average for precipitation (SPI12) in Ullungdo-Island over the period 1966-1997: ▲1976, ▼1988.

extended abnormally northward near the eastern Korean Peninsula and did not form in the vicinity of Ullungdo-Island, and the Tsushima Warm Current Thermal Front, originating from the southeastern part of the Korean Peninsula, moved northward and coincided with the Polar Front (Gong *et al.*, 1985) (Fig. 2).

MLD increased in 1976 and then fluctuated about 40% deeper than pre-1976 (Fig. 3a). The mean MLD estimates were significantly different between the two periods of 1961-1975 and

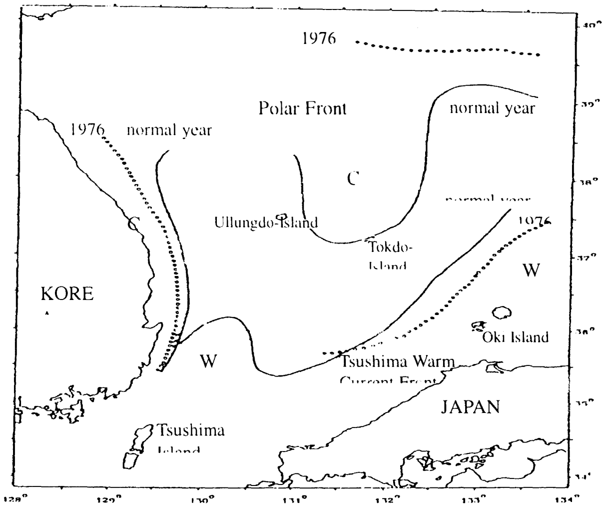

Figure 2. Distributions of thermal fronts in the East Sea. The annual average position of the thermal front in 1976 is an abnormally warm type. W denotes high temperature region and C is low temperature region (modified from Gong *et al.*, 1985).

1976-1990 ($P<0.05$). Chlorophyll biomass in the East Sea showed small interannual variations during 1961-1990, being relatively high in the mid 1960s. The March-May mean chlorophyll *a* concentration shows a declining tendency during the period of 1976-1990 compared to the period of 1961-1975, however, it was not significantly different at $\alpha = 0.05$ ($P<0.1$) (Fig. 3b). The annual biomass of zooplankton showed a small declining trend up to 1988. Since then, however, the biomass of zooplankton has doubled, showing a significant difference between the two periods (pre- and post-1988, $P<0.05$) (Fig. 3c).

The annual catches of 11 major commercial fisheries species showed long-term variations from the mid 1970s to the mid 1980s in Korean waters. Of these, walleye pollock (*Theragra chalcogramma*), sardine (*Sardinops melanosticta*), mackerel (*Scomber japonicus*), Spanish mackerel (*Scomberomorus niphonius*), anchovy (*Engraulis japonica*), corvenias (*Pseudo sciaena spp.*) and sea eel (*Conger myriaster*) increased after 1976 ($P<0.01$). Saury (*Cololabis saira*) declined by an average of about 70% ($P<0.01$) between 1960-1975 and 1976-1987 (Table 1). Also, the catches of squid (*Todarodes pacificus*), mackerel, corvenias, jack mackerel (*Trachurus japonicus*), sea eel and herring (*Clupea pallasi*) increased after 1988 ($P<0.05$). Especially jack mackerel and herring exhibited a marked increase during the period 1988-1996 that were 3.2 and 7.4 times greater than the period of 1976-1987 ($P<0.01$). Walleye pollock and saury declined substantially by 6.0 and 3.4 folds, respectively ($P<0.01$). Time series for these 11 stocks which exhibited the decadal event were examined by coefficients of variation (CV) for the step 1 change (between 1960-1975 and 1976-1987) and the step 2 change (between 1976-1987 and 1988-1996) (Table 2). Of these, two stocks exhibited high CVs during the period 1976-1987 that were greater than the pre-1976 level, but only saury exhibited an increase in variation by more than 50%. Nine stocks exhibited lower CVs for the post-1976 period than the pre-1976 period; stocks that decreased by more than 50% in variability were anchovy, mackerel, corvenias and sardine. In the step 2 change, no stocks exhibited more than 50% increase in variation. Only herring showed lower CVs for the period 1988-1996 than during the 1976-1987 period by more than 50%.

Time series of annual catches for 6 stocks of pelagic warm water fish were examined based on the correlation analyses (Table 3). Sardine and anchovy versus Spanish mackerel exhibited high positive correlations in annual catches overall from 1960 to 1996. Catches of saury had a negative correlation with those of sardine, Spanish mackerel, anchovy and mackerel during the overall period. Both catches of sardine and Spanish mackerel had positive correlations with those of anchovy and mackerel during the years 1960-1975, whereas jack mackerel had a negative correlation with anchovy and mackerel for the 1960-1975 period. During the period 1976-1987, sardine showed a strong positive correlation with Spanish mackerel, however both of these stocks showed a strong negative correlation with saury. During the period 1988-1996, sardine and Spanish mackerel exhibited negative correlations with both anchovy and mackerel. Of these stocks the most notable negative correlation was observed between sardine and anchovy (r=-0.8295, $P<0.01$), whereas mackerel exhibited a strong positive correlation with saury for the post-1988 period. Time series of catches for cold water species were also examined. Walleye pollock had a negative correlation with herring during the period of 1976-1988.

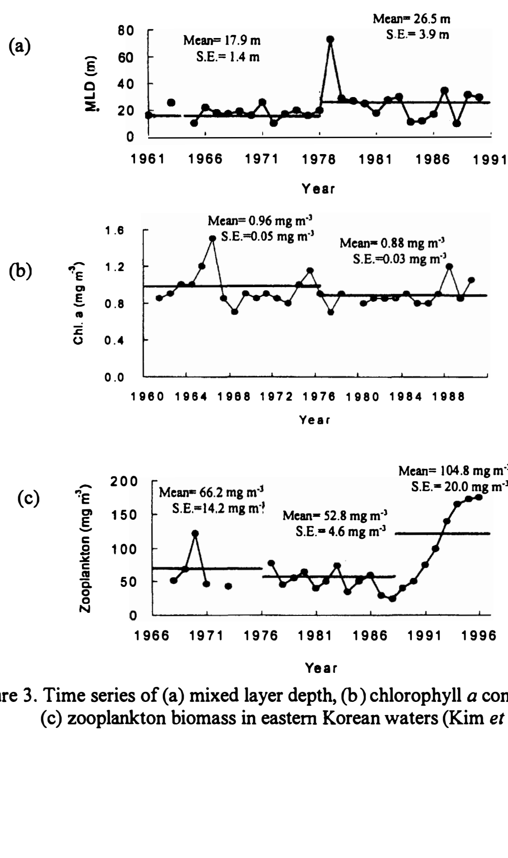

Figure 3. Time series of (a) mixed layer depth, (b) chlorophyll *a* concentration, (c) zooplankton biomass in eastern Korean waters (Kim *et al.*, 1998).

Table 1. Difference in standardized annual catch of major commercial fish species in Korean waters for the three periods (1960-1975, 1976-1987, 1988-1996)[#]

Stock	Average			Step 1 (1960-75 vs. 1976-87)		Step 2 (1976-87 vs. 1988-96)	
	1960-1975	1976-1987	1988-1996	Difference	P-value	Difference	P-value
Walleye pollock	0.164	0.595	0.099	0.431	0.0000	-0.496	0.0000
Anchovy	0.311	0.649	0.748	0.338	0.0000	0.099	NS*
Mackerel	0.074	0.243	0.436	0.170	0.0000	0.193	0.021
Corvenias	0.100	0.523	0.833	0.423	0.0000	0.310	0.0003
Sea eel	0.116	0.425	0.746	0.309	0.0000	0.321	0.0003
Squid	0.254	0.303	0.604	0.048	NS*	0.302	0.0047
Herring	0.164	0.081	0.601	-0.083	NS*	0.520	0.0001
Jack mackerel	0.259	0.202	0.638	-0.057	NS*	0.436	0.0008
Sardine	0.006	0.483	0.373	0.481	0.0001	-0.110	NS*
Spanish mackerel	0.213	0.527	0.578	0.315	0.0002	0.051	NS*
Saury	0.687	0.314	0.092	-0.373	0.0003	-0.222	0.0009

[#] The significance of the the difference between the two time periods was evaluated based on Student's t-test using MINITAB Release 1.0

[*] NS, not statistically significant at $\alpha=0.05$

Table 2. Coefficients of variation in annual catch of major commercial fish species in Korean waters during the three periods, and % changes in coefficients of variation for the step 1 (1960-75 vs. 1976-87) and step 2 (1976-87 vs. 1988-96) in Korean waters

Stock	Coefficient of Variation				Step 1	Step 2
	Overall	1960-1975	1976-1987	1988-1996	% change-CV	% change-CV
Walleye pollock	0.88	0.61	0.34	0.40	-31 %	7 %
Anchovy	0.47	0.58	0.14	0.24	-94 %	21 %
Mackerel	0.89	1.07	0.18	0.54	-100 %	40 %
Corvenias	0.80	1.39	0.18	0.22	-152 %	4 %
Sea eel	0.76	0.62	0.44	0.16	-24 %	-36 %
Squid	0.57	0.35	0.26	0.44	-15 %	32 %
Herring	1.18	1.60	1.04	0.25	-47 %	-67 %
Jack mackerel	0.81	0.87	0.54	0.44	-40 %	12 %
Sardine	1.29	2.33	0.65	0.87	-131 %	17 %
Spanish mackerel	0.62	0.39	0.42	0.46	5 %	6 %
Saury	0.76	0.28	0.87	0.76	77 %	-15 %

Table 3. Correlation coefficients between pelagic warm water fish stocks during the three periods (1960-75, 1976-87, 1988-96) in Korean waters

Overall	Sardine	Anchovy	Mackerel	Jack mackerel	Spanish mackerel
Anchovy	0.2592				
Mackerel	0.2053	0.7477			
Jack mackerel	0.2108	0.1733	0.3314		
Spanish mackerel	0.7512	0.5045	0.3013	0.2391	
Saury	-0.6857	-0.6114	-0.5209	-0.4874	-0.6772
1960-1975					
Anchovy	0.5287				
Mackerel	0.5303	0.7546			
Jack mackerel	-0.2753	-0.5173	-0.5975		
Spanish mackerel	-0.0199	0.5117	0.5170	-0.3869	
Saury	-0.0695	0.1614	0.1761	0.0023	0.4322
1976-1987					
Anchovy	0.1625				
Mackerel	0.0700	-0.0944			
Jack mackerel	0.5602	-0.3455	0.0388		
Spanish mackerel	0.8183	0.4403	-0.0887	0.1284	
Saury	-0.7592	-0.3102	0.2028	-0.4138	-0.7146
1988-1996					
Anchovy	-0.8295				
Mackerel	-0.3796	0.5367			
Jack mackerel	0.1542	-0.1820	-0.1585		
Spanish mackerel	0.4509	-0.5062	-0.5377	0.0175	
Saury	-0.1803	0.3530	0.7126	-0.6863	-0.2051

The pattern of catches with respect to the regime shifts was classified into three types (Fig. 4) as follows: (1) a notable peak from the mid 1970s to the late 1980s such as the catches of walleye pollock, sardine, and Spanish mackerel (Type A), (2) two tiered increases after 1976 and once again after 1988 such as in mackerel, anchovy, corvenias, and sea eel (Type B), (3) low in 1976 and an increase after 1988 such as in herring, jack mackerel, and squid (Type C).

DISCUSSION

Climate shifts in 1976/77 and 1987/88 had significantly changed marine ecosystem and fisheries resources in the North Pacific (Polovina *et al.*, 1994). Our meteorological analyses of precipitation suggested that the decadal climate shifts in Korea that occurred in 1976/77 and 1987/88 responded to the global regime shifts. The climate shifts in Korea changed oceanographic conditions, such as the position of the thermal front, ocean mixed layer depth, secondary production, and species composition and production of fisheries resources during these periods.

Positions of the thermal fronts are considered to correspond to horizontal gradients greater than 0.1°/mile of water temperature. In 1976, because of the predominance of the East

Korean Warm Current and the recession of the coastal low temperature water, the thermal

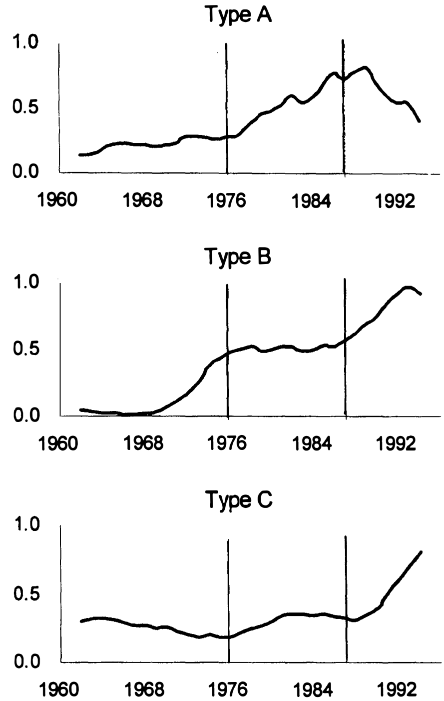

Figure 4. Three types of time series of catches for major commercial fish stocks in Korean waters. All the catches were rescaled to unit maximum. Type A is 5-year moving average of catch in spanish mackerel, Type B is that in corvenias, and Type C is that in squid.

front extended northward near the east of the Korean Peninsula and corresponded to the Polar Front off the north Korean Peninsula. In addition when the warm current water was dominant in 1976, the Tsushima Warm Current Thermal Front moved northward and coincided with the Polar Front (Gong, *et al.*, 1985).

It seems that control of timing and duration of the North Pacific regime shifts can be sought in the dynamics of El Nino/Southern Oscillation (ENSO) and their effects on atmospheric pressure distribution and circulation in the Northern Hemisphere (Wooster and Hollowed, 1995). Ropelewski and Halpert (1986, 1987) and Ropelewski *et al.* (1989) observed decadal variations of precipitation that were governed by teleconnections with ENSO on global and regional scales. Hager (1995) asserted that drought occurrence in Indonesia and the Philippines was associated with identifiable ENSO events. Therefore, the variation of precipitation may well reflect the North Pacific regime shifts.

Precipitation during the period 1976-1988 may have increased due to the intensification of the low pressure system above Korean waters. This low pressure system would bring stronger wind stress or storms, resulting in a deeper MLD. Because MLD was deeper than critical depth (D_{cr}), assuming that it is constant, and then planktons went down below the D_{cr},

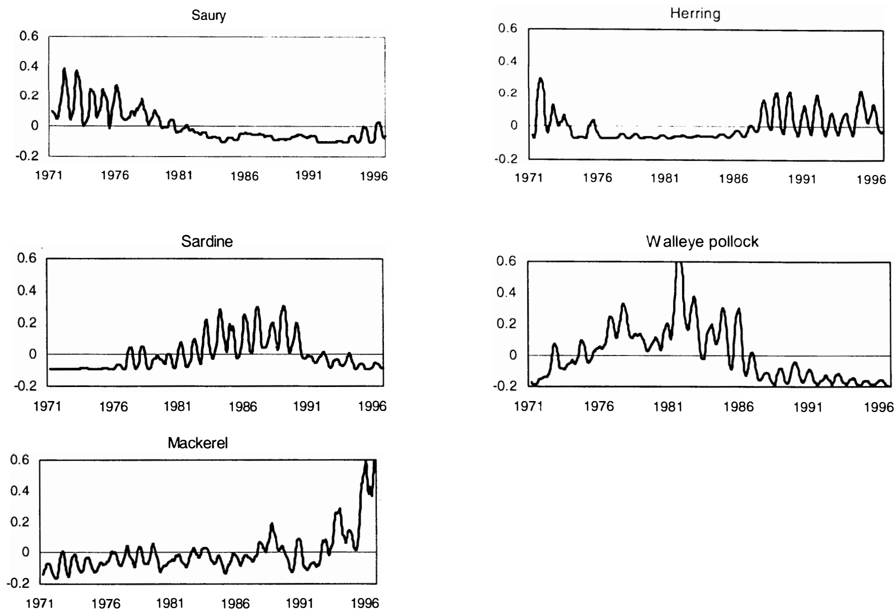

Figure 5. Species compositions in pelagic warm water fish (left-hand) and cold water fish (right-hand) stocks. Solid lines are 6-month moving averages.

phytoplankton abundance and zooplankton biomass should have declined during the period of 1976-1988 as explained by Sverdrup (1953). The interannual variation of the chlorophyll *a* in the East Sea coincided with the variation in the West Pacific which was examined with transparency data by Sugimoto and Tadokoro (1997). The biomass of zooplankton, however, showed a marked increase after the early 1990s (Fig. 3c). It is likelly that these marine physical and biological changes would have triggered changes in the productivity of fisheries resources.

Also due to impacts of regime shifts in 1976/77 and 1987/88, changes in species compositions occurred, that is, the saury population was replaced by sardine and then by mackerel in turn in warm water areas, and herring was replaced by walleye pollock in cold water areas (Fig. 5) (Zhang and Lee, 1998a). The production of sardine, mackerel, jack mackerel and walleye pollock in the Far Eastern Pacific showed similar patterns in response to the global regime shifts during the years 1976-1988. In particular, the production of sardine in Korean and Japanese waters and those of walleye pollock in North Korean and Russian waters had very similar patterns (Zhang and Lee, 1998b). So far, the ecological processes of these patterns are not examined yet, and thus it is necessary to study the causes and mechanisms of these changes in catches by the species group.

However, these fluctuations in catches could be affected by the intensity of fishing operations, so it is necessary to make sure whether the changes are due solely to regime shifts, or due to fishing intensity also, or both simultaneously. Changes in food availability in response to global regime shifts may result in changes in species abundance and distribution (U.S. GLOBEC, 1994). Such changes may cascade throughout the food web, ultimately altering population stability in economically important fish species. Therefore, verification of ecological differences through competition for food and/or for space between species is the critical next step to be understood.

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DEVELOPMENT OF EVALUATION METHOD FOR CONSTRUCTING AQUACULTURE HABITATS

Yoshihiro Suenaga[1], Masayuki Fujihara[2], Takashi Sasaki[3] and Koichi Masuda[4]

[1]Kagawa University
Takamatsu, Kagawa JAPAN
suenaga@eng.kagawa-u.ac.jp

[2]College of Agriculture, Ehime University
Matsuyama, Ehime, JAPAN

[3]Kagawa University
Takamatsu, Kagawa JAPAN

[4]College of Science and Technology, Nihon University
Funabashi, Chiba, JAPAN

ABSTRACT

Recently many coastal developments have caused changes in physical and biological marine environments. Many kinds of artificial reefs have been developed and sunken in the coastal marine area in Japan. There are few effective methods of planning nursery grounds.

To establish more useful methods for creating aquaculture habitats by quantitative evaluation, the crucial factors on constructing aquaculture habitats were evaluated based on field experiments which were conducted at the west coast of Kii Peninsula, Japan twice (summer and winter) in 1997. We propose more appropriate structures and systems for creating aquaculture habitats based on the results of field experiments and numerical simulations. Now we are researching biological effects of proposed structures. Habits such as diving have been confirmed to be good.

INTRODUCTION

There are a number of flat fish (*Paralichthys olivaceus*) and shellfish (*Nordotis discus, Turbo cornutus*) aquaculture grounds on the shelf area of the Kii Peninsula, Japan.

Pelagic eggs and larvae are transported from the spawning grounds to the coastal nursery grounds. Some of them, in avoiding the dispersion to the offshore from the shelf, could successfully get to the coastal nurseries before they start to settle down to the bottom. The location of spawning grounds roughly coincides with the results of field experiments that examined distribution area of fish eggs. The success or failure of the transport from spawning grounds to the nurseries could determine year-class strength of the flat fish and shellfish population on these aquaculture grounds (Nakata et al., 1996). In order to clarify the crucial factors affecting the transport process, field research has been conducted a numerical simulation of the eggs and larval transport have been made using a three dimensional current model (Fujihara et al., 1997, Suenaga et al., 1996). This paper aims to describe the process of eggs and larval transport in creating appropriate aquaculture habitats and propose more appropriate structures and systems of constructing aquaculture habitats for aquaculture resources based on the results of field experiments and numerical simulations.

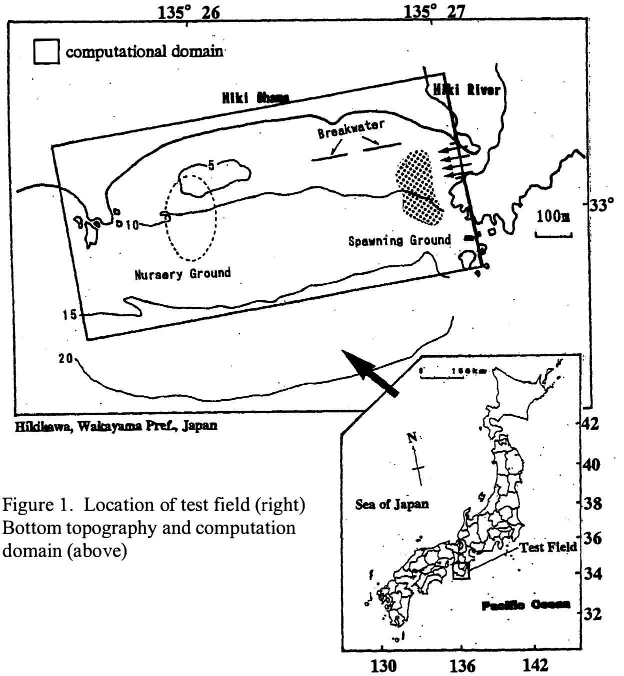

Figure 1. Location of test field (right)
Bottom topography and computation domain (above)

MATERIALS AND METHOD

The location of test field is shown in Figure 1. In field experiments, we measured water quality, biological condition including density of phytoplankton, zooplankton, fish eggs and larvae. Further, buoys were released to visualize water movement (see Figure 2 in this paper). Field experiments showed that low density of phytoplankton and dissolved oxygen were observed around a river mouth. On the other hand, high density of those were observed in an eddy, which appears along the coastal areas less shallow than 15m deep, generated by bottom topography (shown in Table 1 and Figure 3). This is because phytoplankton would have been carried away by river discharge, whereas coastal eddy would contribute to phytoplankton retention on the nursery grounds. From the results of field experiments and numerical simulation, it was found that coastal eddy and river discharge are important factors in creating nursery grounds.

Figure 4 depicts a model area and a schematic flow pattern based on the results of field experiments. For simulating the current system in this area, a three-dimensional model with a horizontal grid size of 25m (22x44 grid points) and vertical resolution of 2 layers

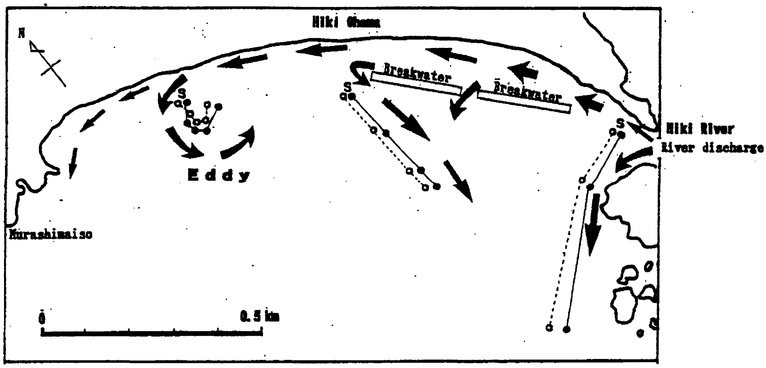

Figure 2. Observed Trajectories of Floating Buoys on November 20, 1997
(Circles indicate the buoy location every 15 minutes.)

(upper: 0-3m, lower: 3m-bottom) was initially developed. The current field was controlled by the inflow from the entrance of the Hiki River. The parameters and their values used for the simulation are listed in Table 2. The inflow velocity was 40cm/s in the lower as the river discharged. Under these conditions, three particles (No. 1,2,3) were located at predicted spawning grounds and all particles were fixed at the depth of 1m. Figure 4 shows the computed particle trajectories from the spawning grounds. The circles in the figure mean the location of egg/larvae at initial times and every 15 minutes thereafter. From the computed particle trajectories, particle No.1 drifted away from the study area within an hour. Particle No. 2 also drifted away within 2 hours. Only particle No. 3 could be transported to coastal nursery grounds through the backside of breakwaters. Coastal nursery grounds where particle No. 3 was transported, it appeared eddy current by cased bottom topography. This movement pattern was very agreeable to the results of field experiments. This suggests that the development of the coastal eddy could contribute to enhancing the larval retention on the nursery grounds. This means that the coastal eddy located in the downstream of the spawning grounds is a probable mechanism for fish and shellfish larvae to remain on the shelf against rather high level of advection in and around the Hiki Ohama.

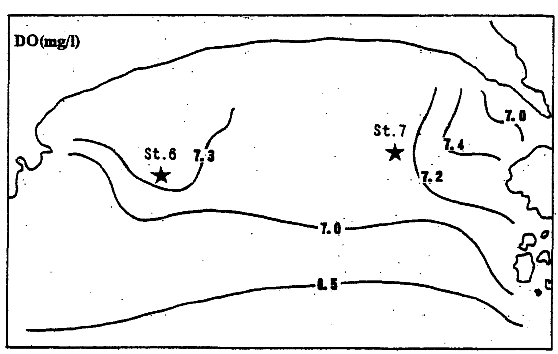

Figure3. Observed Distribution of Dissolved Oxygen on July 3, 1997

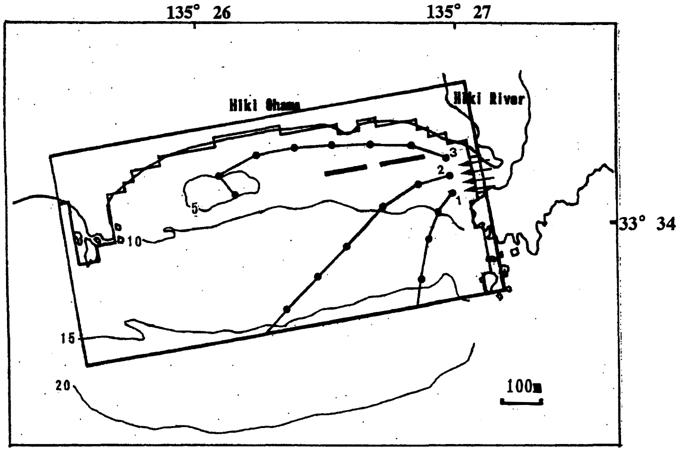

Figure 4. Computed Trajectories of Particles

Table 1. Observed Density of Phytoplankton at St. 6 and 7 in July and November, 1997.

	St. 6		St.7	
Date	July 1997		July 1997	
Amount of Cells	32,560 (cells/l)		10,920 (cells/l)	
Amount of Species	50		18	
Dominant Species	1. Skeletonema costatum	29%	1. Fragilarria sp	56%
	2. Pseudo nitzschia spp.	21%	2. Peridinium bipes	11%
	3. Chaetoceros distans	8%	3. Chaetoceros compressus	6%
	4. Leptocylindrus danicus	5%	4. Chaetoceros affinis	5%
	5. Chaetoceros compressus	4%		
Date	November 1997		November 1997	
Amount of Cells	1,720 (cells/l)		1,180 (cells/l)	
Amount of Species	22		14	
Dominant Species	1. Pseudo-nitzschia spp.	21%	1. Pseudo-nitzschia spp.	19%
	2. Skeletonema costatum	12%	2. Asterionella kariana	15%
	3. Rhizosolenia aiata	12%	3. Leptocylindrus danicus	12%
	4. R. solterfothii	12%		
	5. Chaetoceros affinis	7%		

Table 2. Parameters Used in the Numerical Simulation

Drag coefficient at the sea surface	γ_i^2	=	0.0013
Drag coefficient at the bottom	γ_b^2	=	0.0026
Horizontal eddy viscosity	$N_{x,y}$	=	$10 m^2/s$
Vertical eddy viscosity	N_z	=	$1 cm^2/s$
Horizontal diffusivity	$K_{x,y}$	=	$10 m^2/s$
Vertical diffusivity	K_z	=	$1 cm^2/s$
Coriolis parameter	F_0	=	$7.92X10^{-5}/s$

RESULTS

Figure 5. depicts aquaculture structures proposed in the present study. We call them "Aqua-cube" and "Natural harmonic Reef". The size of the Aqua-cube is 1.8m in length and 1.28 m in height. The dimensions of a natural harmonic reef are 6.0m in width, 6.0 m in length and 3.0 m in height. This structure is combined by square units with natural stones. Natural stones have the power to activate living organisms (Sakuta et. al., 1993 and Sakuta et. al., 1987), and by their use, an animate environment is created which is conducive to habitation by living organisms. Figure 6 depicts these structures have confirmed that fish and shellfish are aggregating in and around the structure better than natural reefs. Natural stones with diameters of 40-50 cm were piled up on the structure. These structures have many functions. For example, an artificial reef allows fry, young fish and shellfish to shoal and reside there and they use the reef as a spawning ground where fry and young fish can shoal, grow and spawn. These aquaculture structures provided a feeding environment. Then we proposed appropriate systems of creating aquaculture habitats for marine resources by using the results of field research, calculated results of numerical simulation and proposed aquaculture structures shown in Figure 7. Natural harmonic reef is sunken in a marine location offshore at depths of 10-20m in the predicted spawning grounds. This structure can induce up-welling current for eggs and larval transport. Aqua-cube is sunken in the coastal eddy grounds where it appears that the eddy is induced by bottom topography. Thus, if the locations of spawning or nursery grounds are known, we could estimate the other and develop and improve more useful fishery grounds by using this system including a numerical simulation model.

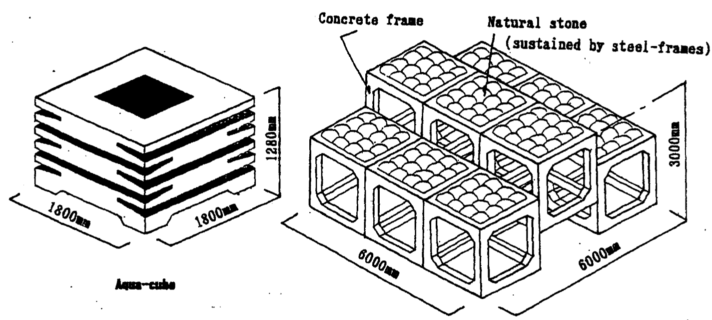

Figure 5. Proposed Artificial Reefs; Aqua-cube (left), Natural Harmonic Reef (right)

DISCUSSION

This study has revealed that a coastal eddy, which appears on the bottom topography in the down stream of the spawning site and river discharge, would contribute to larval retention in the nursery grounds and prevent the larvae from flowing offshore. Future investigations should focus on the dynamic behavior of the eddy and its implications for egg and larval transport and distribution in this region. It is also necessary to take vertical movement of the eggs and larvae and the development of locomotive ability of the larvae into the model for the seasonal wind effects on the transport and subsequent recruitment. In addition, we'll conduct continuous investigation into the biological effects of proposed structures because it has been confirmed that they are becoming good habitats for many kinds of marine resources.

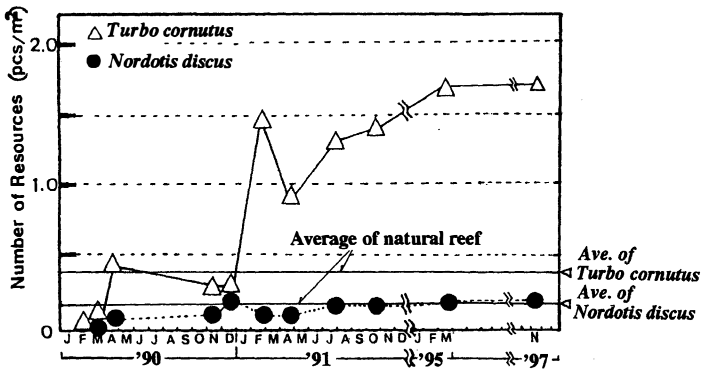

Figure 6. Yearly Changes in Marine Resources on the Proposed Structures

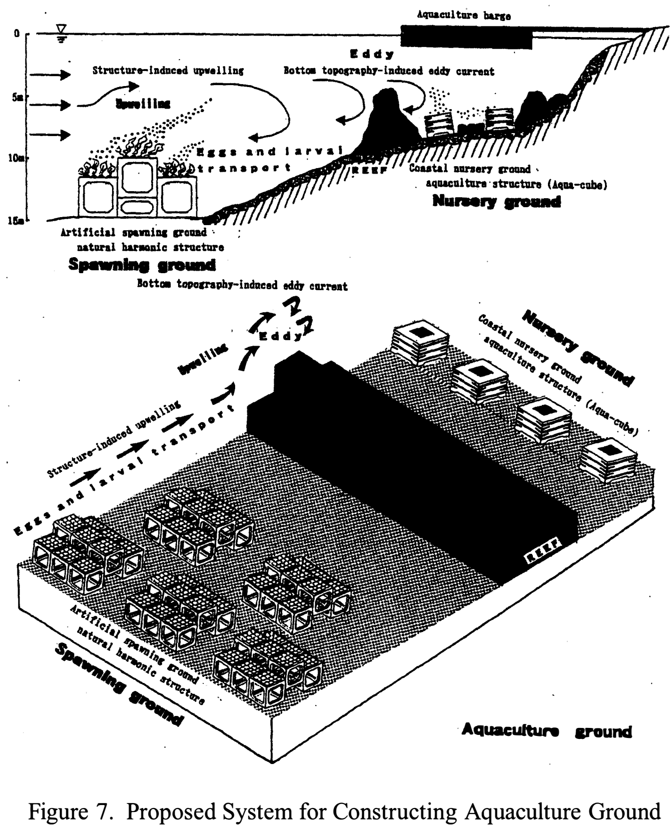

Figure 7. Proposed System for Constructing Aquaculture Ground

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A STUDY ON THE PHYSIOLOGICAL EFFECTS OF ULTRA-SONIC WAVES OF COASTAL AREA ON HUMAN BRAIN WAVES

Jong In Choi, Shinichiro Kanzaki and Kenji Hotta

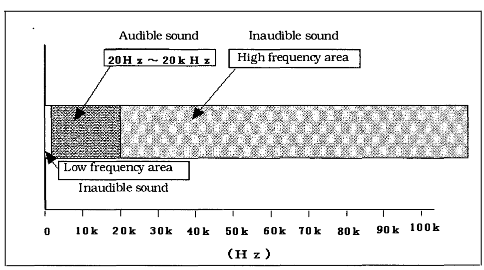
Dept. of Oceanic Architecture and Engineering, College of Science and Technology
Nihon University, JAPAN
hotta@neptune.ocean.cst.nihon-u.ac.jp

ABSTRACT

In this study, an experiment was conducted on the effects of ultrasonic waves contained in the sounds of waves of coastal regions on human brain waves. The experiment involved having subjects listen to sounds containing ultrasonic waves and those not containing ultrasonic waves followed by measurement of brain wave response at those times. As a result, brain waves (• wave band) were confirmed to be activated by sounds containing ultrasonic waves.

INTRODUCTION

The sensory organs by which humans receive information from the outside world consist of the so-called five senses (sight, sound, touch, smell and taste). The amount of information obtained from "sound" that is recognized through the sense of hearing is quite large, second only to that obtained from the sense of sight. This sense of hearing is an important environmental factor that affects the degree of comfort or discomfort in our daily lives. The sounds that exist in nature can be broadly classified as shown in Fig. 1 into those of the audible region (20 Hz to 20 kHz), which can be heard by the human ear, and those of the inaudible region (20 kHz and above), which cannot be heard by the human ear.



Fig,1 Frequency bandwidths of sound

It has been reported that the human sense of hearing has the capacity to detect frequencies far in excess of 20 kHz (ultrasonic region) not only by tympanic vibrations heard with the ear, but also by the use of bone transmission of other portions of the ear, the skull and skin, and the hair on the head as well as synthetic information with the sense of touch (Ohashi and Nishina 1991, Nadaoka et.al.1992) It has also been reported in the field of music research that the high-frequency components (ultrasonic waves) contained in music produced by ethnic musical instruments have a beneficial effect on human brain waves (Nishina et.al.1992).

In addition, the sounds that exist in nature and live sounds of musical instruments not only contain audible sounds, but also high-frequency components (ultrasonic waves), and these are considered to enhance the sense of pleasure. Coastal regions are blessed with a sound environment that is more extensive than that found in inland regions where people normally lives. Although the "sound of waves" has been assessed as one of the elements of appeal with respect to the enjoyment offered by coastal regions, there are numerous aspects of its special nature that remain unclear.

In this study, we focused our attention on wave sounds that are considered to be one of the representative natural environmental sounds found in coastal regions to clarify the effects of the presence or absence of ultrasonic waves contained in those sounds, their sound pressure and so forth on human physiological response (brain waves). Hearing experiments were conducted on subjects by adding natural ultrasonic waves (sampled from wave sounds) to audible sounds (wave sounds), and comparing and studying the physiological response (brain waves) of the subjects according to frequency and sound pressure. The results were then used to determine whether ultrasonic waves can be a factor that enhance the level of pleasure of human beings.

EXPERIMENTAL METHOD

The experiment consisted of having subjects listen to ultrasonic waves in wave sounds recorded at coastal regions followed by measuring their brain waves at that time. Furthermore, a preliminary experiment was conducted prior to the actual experiment. In the preliminary experiment, the characteristics of brain wave response to sound stimulation was investigated. In the actual experiment, the response of brain waves to a sound source combining audible sounds and ultrasonic waves was investigated. Details of the subjects and the configuration of the experiment are described below.

Subjects

The subjects were conditioned with respect to the three restrictions of prohibiting consumption of alcohol and beverages containing caffeine such as coffee, black tea, green tea or cola on the day of the experiment, and getting at least 6 hours of sleep on the day before the experiment . The experiment was conducted with the subjects wearing eye masks and sitting in chairs.

Measured Parameters

Brain waves: Brain waves were measured by means of electrodes attached to the left and right sides of the forehead (in accordance with IBVA). Measuring for the four bands consisting of • waves (0.5-4.0 Hz), • waves (4.0-8.0 Hz), • waves (8.0-13.0 Hz) and • waves (13.0-30.0 Hz).

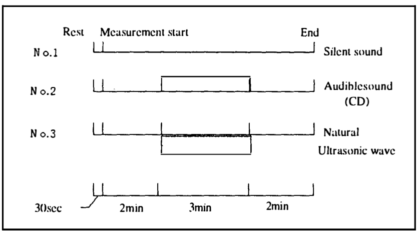
Sound Sources

Preliminary Experiment: The three types of experiments described below were conducted allowing 7 minutes for each measurement in order to view the brain wave response to sound stimulation (Fig. 2).

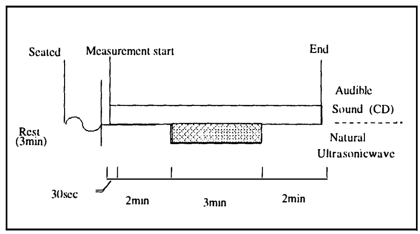
No. 1: The diagram of measuring brain waves for 7 minutes in the absence of sound. This diagram was used to observe brain wave fluctuations in the absence of stimulation.

No. 2: Subjects presented with audible sound (CD) for 3 minutes following 2 minutes in the absence of sound after which the absence of sound was continued for the final 2 minutes. This was done to observe the response of brain waves to stimulation in the form of audible sound.

No. 3: Subjects presented with natural ultrasonic waves for 3 minutes following 2 minutes in the absence of sound after which the absence of sound was continued for the final 2 minutes. This was done to observe the response of brain waves to stimulation in the form of natural ultrasonic waves.



Fig,2 exposure time of sound stimulation



Fig,3 Exposure time of composite sound sources

Actual Experiment: In experiments combining audible sound (CD) with recorded ultrasonic waves, 7 minutes were allowed for each measurement in the same manner as the preliminary experiment (Fig. 3).

Audible sound and natural ultrasonic waves were used for the presented sound sources. A commercially available compact disk was used for the audible sound (20 Hz to 20 kHz) ("Ecology Natural Sound Series - Sound of Surf Break", CBS/Sony Records, edited CD containing wave sounds recorded in the Seychelles, New Caledonia, Okinawa and Tahiti).

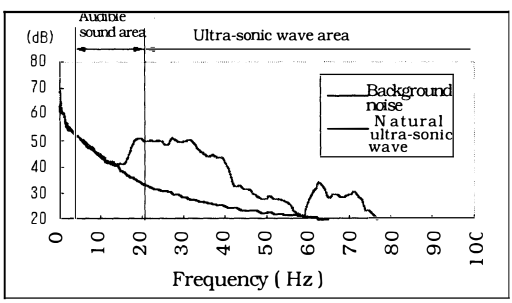


Fig.4 Frequency characteristics of natural ultra-sonic wave

Ultrasonic waves recorded at a natural coastline were used for the high-frequency ultrasonic waves (18 kHz to 100 kHz). The ultrasonic waves were recorded on October 12, 1993 along the Emikichiura coastline in Kamogawa city, Chiba prefecture. The recording equipment consisted of a microphone (Rion UC-29), noise meter (Rion NA-40), filter (Rion SA-33D), FFT analyzer (Ono Instruments CF-360z) and data recorder (Teac XR-5000WB). The frequency characteristics of the presented ultrasonic waves are shown in (Fig. 4).

Analytical Method

Brain wave analysis was performed by Fast Fourier Transformation (FFT) of the brain waves obtained by IBVA. In addition to calculating the time average of the spectra at 30 second intervals for the detected brain waves, the amounts of activity of a and • waves (amounts of increase or decrease) were determined for comparison purposes based on the brain wave response average during resting.

RESULTS AND DISCUSSION

Preliminary Experiment

The effects of sound stimulation on brain waves were examined with respect to brain wave fluctuations while focusing on the • wave band (8 Hz to 13 Hz), which is an indicator of degree of relaxation, sense of calmness and ability to concentrate when awake, and • wave band (13 Hz to 30 Hz), which appear during thinking and exercise, etc.

Table 1 indicates the changes in brain waves under the respective conditions of 1) presenting the subjects with the absence of sound, 2) presenting the subjects with audible sound, and 3) presenting the subjects with ultrasonic waves. This table shows the number of subjects in which • waves increased and that increase exceeded the wave increase, the time at which this occurred, and the mean of the rate of change (increase or decrease) of • waves of the subjects. As can be understood from this table, brain wave responses for both • waves and • waves were unremarkable in the cases of the absence of sound and audible sound only. On the other hand, when subjects were exposed to ultrasonic waves, the • wave band was

Table 1. Number of wave vitalized subjects and average of increment

	Male (/7)	Female (/4)	Male (/7)	Female (/4)
Silent sound	0	1	−1.01%	−1.26%
Audible sound	2	0	−1.00%	−0.49%
Ultrasonic wave	4	1	+8.12%	+2.68%

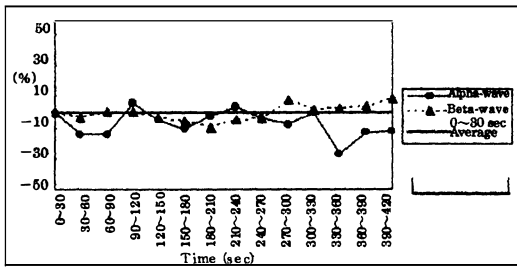


Figure 5. Increment Rate of Brain Waves (Silent Sound)

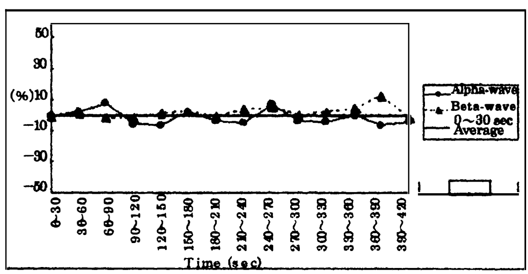


Figure 6. Increment rate of brain waves (Audible Sound)

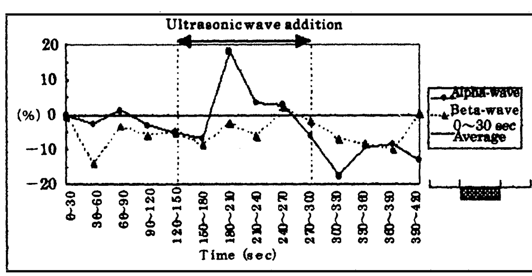


Figure 7. Silent sound and nature ultrasonic wave

observed to be activated in 5 of 11 subjects. Figs. 5, 6and 7 indicate examples of the appearance of brain waves under each condition.

Actual Experiment

In the actual experiment, after allowing the subjects to listen to audible sound continuously for 2 minutes, the subjects were exposed to ultrasonic waves for 3 minutes and then finally exposed to audible sound for 2 minutes (Table 2). In 15 of the 23 subjects, • wave activity was observed to be more active than • wave activity. In general, the • wave band is activated by pleasant sound stimulation, and is inhibited as a result of being presented with noise and unpleasant sounds. Conversely, the • wave band is known to increase when exposed to noise and unpleasant sounds. This may indicate that the • wave band has been activated as a result of exposing the subjects to the audible sound range containing natural ultrasonic waves. Although it is known that there are differences in the brain between men and women, as can be understood from Table 1, differences were also observed in the rate of change of • waves between male and female that participated in this experiment.

Table 2 α and β wave increment by naturae ultrasonic waves.

No.of Subject	Increment of α wave.(%)	Increment of β wave.(%)	Evaluation
1	+118.00	+ 25.13	○
2	+ 68.65	+ 10.56	○
3	+ 46.03	+ 23.68	○
4	+ 39.60	+ 1.20	○
5	+ 34.03	− 1.03	○
⑥	+ 26.04	+ 36.19	
⑦	+ 21.73	+ 2.30	○
8	+ 20.40	− 0.60	○
9	+ 17.06	− 24.97	○
⑩	+ 13.30	+ 10.40	○
⑪	+ 12.75	+ 13.07	
12	+ 8.40	− 0.80	○
⑬	+ 7.02	+ 6.93	○
14	+ 6.46	+ 6.52	
15	+ 5.00	+ 25.20	
16	− 0.60	− 2.80	○
⑰	− 1.60	− 3.80	
⑱	− 2.50	− 4.10	○
19	− 4.00	− 6.40	○
20	− 6.60	− 13.00	○
㉑	− 9.90	− 8.80	
㉒	− 10.60	+ 5.10	
㉓	− 11.40	+ 0.10	

○··· Female

In addition, a certain amount of time was required for brain waves in responding to ultrasonic waves. It was observed that the response persisted having even after exposure was stopped. This response delay was observed in all subjects the mean duration of delay 38.09 seconds. Therefore, in order to calculate the amount of activity more accurately, the amount of brain wave activity was determined while taking into consideration this time delay.

Fig. 8 shows a typical example of a subject in which brain wave activity was activated as determined by spectral analysis of brain wave forms during a single measurement. Brain wave voltage (•V) is plotted on the vertical axis, while the wave frequency is plotted on the horizontal axis. As can be understood from Fig. 8, a time delay can be observed in the response.

Figs. 9 ,10 and 11 show the increase or decrease in brain wave activities by the exposure to ultrasonic waves.

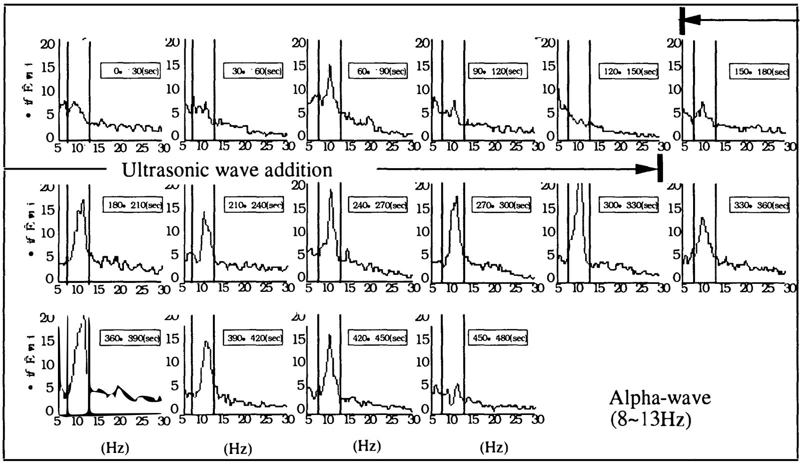


Figure 8. Change of Wave Spectrum Example of a Wave in One Measurement

In summary, 1) a tendency was observed in which human brain waves are activated by exposure to ultrasonic waves, and this tendency was particularly evident for • wave activity; 2) a delay of 38.09 seconds on average was observed in brain wave response time following exposure to ultrasonic waves; and even after exposure of ultrasonic wave was stopped response of • brain-wave continued for a while, and 3) differences in the states of brain wave activity were observed between male and female subjects.

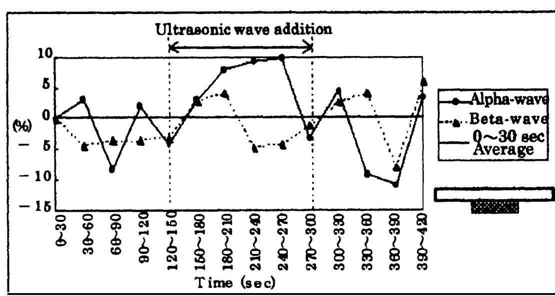


Figure 9. Example of the vitalized α wave

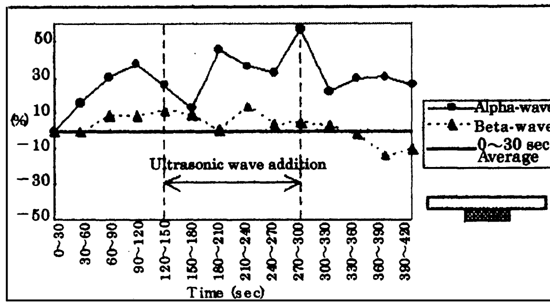


Figure 10. Example of the vitalized α wave (2)

In general, • wave activity is considered to represent states in which human beings are relaxed and calm. However, assessment of relaxation and calmness based on the state of these brain waves is not understood in detail at the present time. As the analysis attempted in this study was conducted only from a quantitative viewpoint, it may be necessary to analyze other physiological indicators, such as measurement of heart rate and skin electrical potential, are also important. At present, these are being conducted in conjunction with psychological analyses.

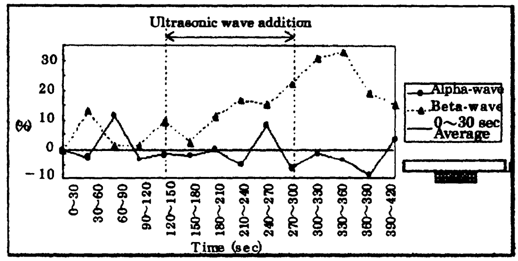


Figure 11. Example of the vitalized α wave (3)

Various sound environments exist in coastal regions. These include the gurgling sounds of fountains and brooks and the sound of the wind rustling the trees, and ultrasonic waves are contained in these sounds as well. Although this experiment focused primarily on an analysis of wave sounds while adding artificial ultrasonic waves, the results will serve as an effective reference for utilizing coastal regions in the future while verifying case studies of environmental factors that exist in coastal regions have healing effects on human beings.

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FACTORS CAUSING HYDROGEN SULFIDE AND ITS CONTROL MEASURES IN FISH-PROCESSING DRAINAGE

Isao Yamamoto[1], Koji Mitsuhashi[1], Shoichi Ito[1], Etsuo Fukushiro[2], Takayoshi Mishijma[2] and Toshio Mikami[2]

[1]The Japanese Institute of Technology on Fishing Ports and Communities
Tokyo, JAPAN

[2]Shimane Prefecture Office
Shimane, JAPAN

ABSTRACT

Most of the wastewater treatment facilities suffer, more or less, from inefficiency and corrosion due to hydrogen sulfide after start-up. This brings about the problems such as increase of maintenance cost and serious worse working conditions caused mainly by stench. This paper presents the investigation on the factors causing hydrogen sulfide in wastewater mainly from the fish-processing industry in Hamada fishing port and provides controls through analysis and available data collected.

OUTLINE OF SITE CONDITIONS

Features of Hamada Fish-Processing Drainage Treatment Facility

The treatment facility in Hamada fish-processing industry complex is located within Hamada fishing port in the western part of Shimane Prefecture. This facility started operation in September 1991 for purifying water from the fishing port. This facility handles all the wastewater discharged from 31 units of the processing plants dealing with processed marine products, fresh fish, refrigeration, cargo handling and fishmeal. The total water volume the sewer was designed to hold is 1,650 m^3 per day, specifying respective volume for high and low concentration groups. The treatment method covers three steps, namely pressure flotation, activated sludge process and contact aeration process. The designed and measured water values are shown in Table-1.

Problems of Pumping System

The drainage is gathered at the facility by the pumping system through the screens at each processing plant. Therefore, hydrogen sulfides generated in the anaerobic conditions in the pipes are corroding pre-treatment equipment in the facility.

Table 1. Water Quality

	Designed Values		Measured Values	
	Inflow	Discharge	Inflow	Discharge
BOD mg/1	High 5,000 Low 1,300	20	153~1,970 537~1,319	1.8~20
COD mg/1	High Low	40	919~1,665 263~853	16~30
SS mg/1	High 1,300 Low 530	40	946~1,046 276~546	1.6~16
n-hex mg/1	High 490 Low 110	30	194~344 35~91	0.2~21

ACTION AND GENERATION OF HYDROGEN SULFIDE

Damage by Hydrogen Sulfide

Hamada treatment facility has corrosion problems with hydrogen sulfide on concrete, metal devices, pipe lines, and electrical equipment.

Mechanism of generation of hydrogen sulfide

The place where the drainage stagnates becomes anaerobic. Sulfite-reducing bacteria then works to reduce the five factors as shown in Figure 1, applying oxygen on sulfate contained in the drainage. Based on such chemical reactions, the drainage conditions enabling the easy generation of hydrogen sulfide have been clarified.

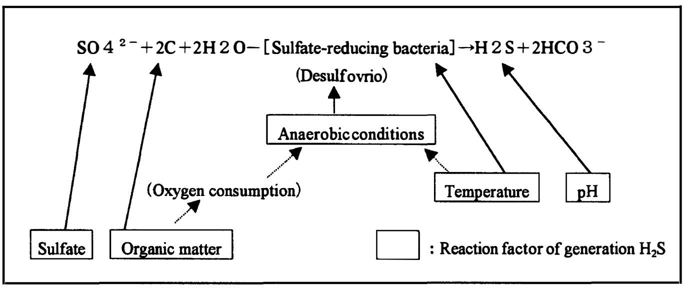

Figure 1. Chemical reaction diagram on generation of hydrogen sulfide

CONDITIONS TO CAUSE EASY GENERATION OF HYDROGEN SULFIDE IN FISH-PROCESSING DRAINAGE TRATMENT

Here is a comparison table between drainage conditions to enable easy generation of hydrogen sulfide and characteristics of fish-processing drainage in Hamada treatment facility.

Table 2. Comparison beweteen generation conditions of hydrogen sulfide and characteristics of fish processing drainage

Drainage conditions to enable easy generation of H_2S	Discharge features of fish-processing drainage treatment facility
1. Organic drainage with high concentration	• Organic concentration is high due to mingling of blood-stained water and fish grease. • Drainage from high concentration processing field flows in.
2. Drainage with much sulfate (Sulfate ion)	• Sulfate ion concentration is high due to mixing of seawater
3. Drainage with anaerobe	• Organic concentration is high, and respiration rate is fast • Water water tends to stagnate in pumping tank
4. Drainage with high temperature	• Temperature is in some cases, high due to heat processing by some industries
5. Drainage with low pH	• Extent of generating H_2S is allowable

Five conditions which may cause hydrogen sulfide generation easily are:

1. High concentration organism: BOD concentration of fish-processing drainage in Hamada is very high, amounting to about 5 to 50 times the value of sewerage, approximately 200 mg/l. This becomes nutrients for bacteria and also accelerates oxygen consumption for anaerobic development.
2. Sulfate (Sulfate Ion): Sulfate ion concentration is 20 to 100 mg/l for sewerage, and sulfate ion amounting to about 2,700 mg/l is included in seawater. Even if 10% mixes with seawater, sulfate ion concentration becomes 3 to 13 times the sewerage value.
3. Anaerobic Condition: In Hamada fish-processing drainage, the respiration rate is fast due to high organic concentration. Expecially during nights, holidays, stormy weather and when not sailing or fishing, little drainage runs and waste water tends to stagnate in the pumping tanks. This accelerates anaerobic conditions. Furthermore, another factor for anaerobic development is that oxygen is not supplied into the slurry pipeline.
4. Temperature: With the increase in temperature, sulfate-reducing bacteria actively reacts and the volume of hydrogen sulfide increases. In the case of Hamada fish-processing drainage, the temperature is high due to heat processing by some industries. Besides fish meal drainage is always high in temperature.
5. pH: The pH value of Hamada fish-processing drainage changes daily with an average range of 6.5~8.5 which indicates the extent to easily cause hydrogen sulfide.

Consequently, Hamada fish-processing drainage provides all of the favorable conditions for easy generation of hydrogen sulfide, and also because of the high concentration level in each condition.

CONDITIONS OF CAUSING HYDROGEN SULFIDE INCREASE IN FISH-PROCESSING DRAINAGE

This survey which studied which conditions will cause the increase of hydrogen sulfide was carried out in Hamada treatment facility.

Method of Survey

As a parameter for this survey, F-H_2S was adopted. This is defined as a supersaturated sulfide to indicate hydrogen sulfide concentration rate diffusing into gas phase by means of mixing, etc. out of dissolved sulfide and to be measured by Head Space method. Regarding a survey method, the relationship between F-H_2S and DO•ORP which is deemed one of the factors to increase hydrogen sulfide was clarified through analysis on the sample water gathered at each pump pit of fresh-fish, cargo-handling, and processing spots. On the other hand, the effect of temperature and seawater dilution was clarified through related experiments.

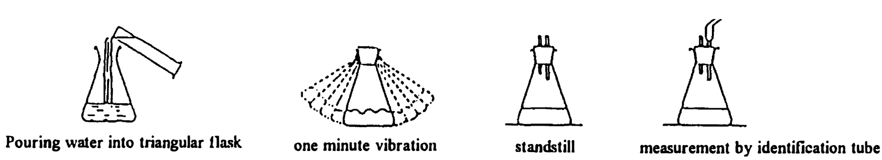

Figure 2. Measurement of F-H_2S by Head Space Method

Survey Results

Relation between F-H_2S and DO• ORP (Analysis Results)

F-H_2S increases in range that DO is less than 2 mg.l and ORP is less than –150 to –200 mV.

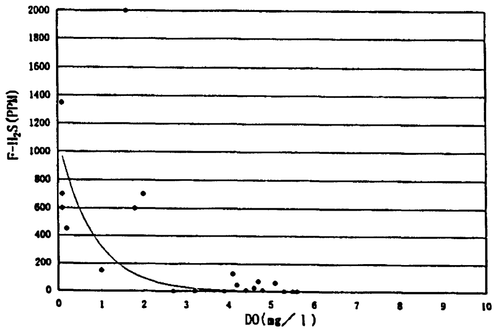

Figure 3 . Relation Between F-H_2S and DO

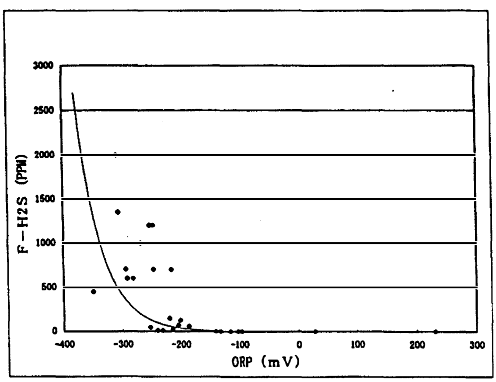

Figure 4. Relation Between F-H_2S and ORP

Relation between F-H_2S and Temperature (Experimental Results)

Non-plant species increase linearly at 10 to 35°C, while plant species increase gradually until 22°C, but rapidly after 22 to 35°C. It is considered an acceleration of the activation of the microorganism. As a result, the increase of temperature is influential in the generation of H_2S. It is assumed that the increase of non-plant species depends on the change in gas solubility.

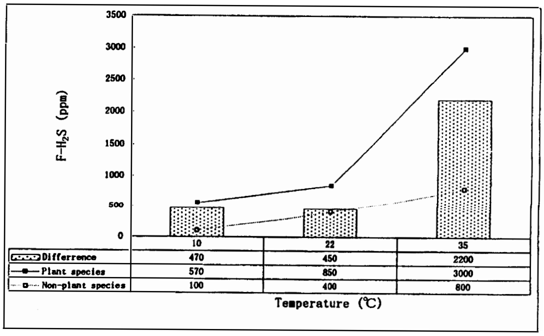

Figure 5. Relation between F-H_2S and Temperature

Relation between F-H_2S and Seawater (Experimental Results)

F-H_2S decreased with fresh water dilution and increased with seawater dilution. The mixing of seawater strongly affected the generation of hydrogen sulfide. Therefore, it is very important to determine how to prevent seawater from mixing in the course of processing at the fish-processing plants in order to control the generation of hydrogen sulfide.

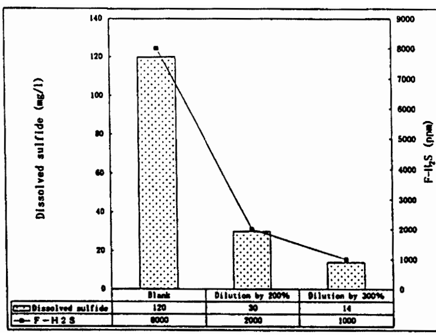

Figure 6. In case of diluting fish processing drainage with fresh water

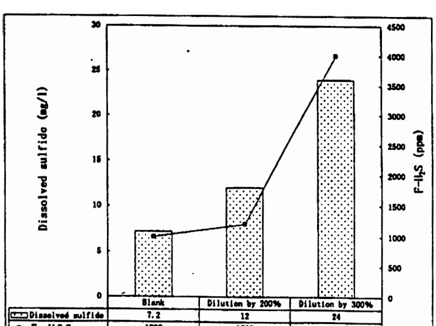

Figure 7. In case of diluting fish processing drainage with seawater

Relationship between F-H^2S and pH Analysis Results)

Hydrogen sulfide increases when the pH level is less than 9 and reaches mostly 100% in acid level. According to the experiment results, F-H_2S increases when the pH level is less than 8.5 and as the pH level approaches the acid level, the bigger the H_2S value.

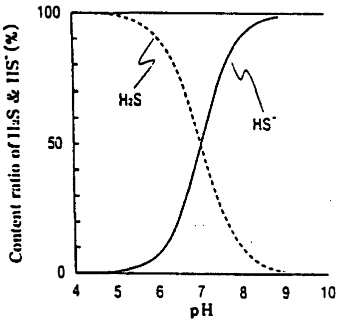

Figure 8. Relation between content ratio and H_2S and HS^-

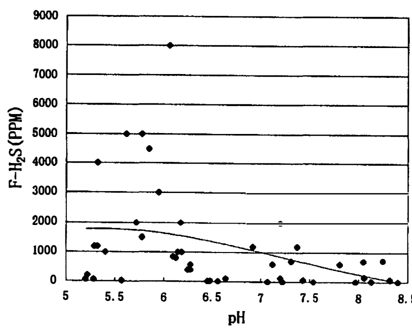

Figure 9. Relation between F-H_2S and pH

CONDITIONS TO CONTORL HYDROGEN SULFIDE

The conditions to control hydrogen sulfide in fish-processing drainage are summarized in Table 3 below.

Table 3. Condition that control hydrogen sulfide at the Hamada Drainage Treatment Facility

1. Deterioration of organic matter concentration	• To control circulation use of water.
2. Deterioration of sulfate ion concentration	• To protect mixing of seawater in a great measure
3. Prevention from anaerobic development	• To maintain DO in drainage at more than 2 mg/l. To make ORP in drainage be more than -150 mV.
4. Deterioration of liquid temperature	• To keep temperature in drainage at less than 20°C
5. pH control	• To prevent pH from acidification

The severeness of item 1 and 2 in Table 3 depends on the management system in the processing plants and cargo-handling yards. With regards to Item 3, hydrogen sulfide does not generate as long as the drainage is maintained under conditions defined in Table 3. As shown in figure 10, the range where S_2 is less than 1 mg/l is limited to the range of ORP being more than −150 mV. On the other hand, S_2 of more than 1 mg/l is concentrated in the range of DO being less than 2 mg/l in distribution, but extended to nearly 5 mg/l level, so correlation between S_2 and DO is not as clear as in the case of ORP. As a result, it is better to use ORP, rather than DO as a control indicator for sulfide.

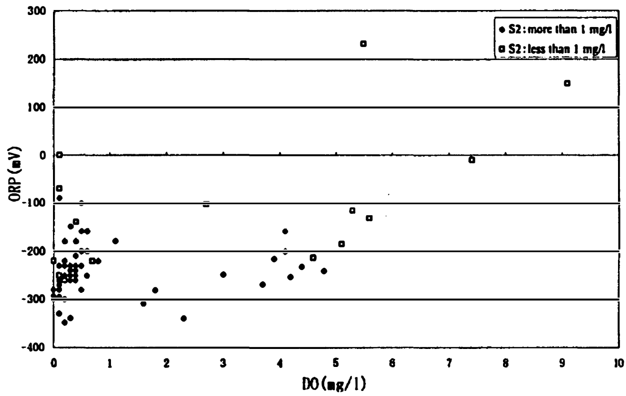

Figure 10. Relation between dissolved sulfide and DO/ORP

Item 4 in Table 3 should be carefully considered, since it is effective in controlling hydrogen sulfide at all times, but counter-productive in the treatment of the microorganisms. Item 5 is a concern when the pH level of greater than 8.5 indicates a high level of hydrogen sulfide, but treatment of the microorganisms may also create some problems in such conditions.

Moreover, since conditions 1-4 depend entirely on the action of sulfide-reducing bacteria, reaction control of such bacteria is the key to preventing the generation of hydrogen sulfide. Hence, it should be noted that in the event hydrogen sulfide generates in fish-processing drainage, hydrogen sulfide concentration becomes high depending on higher levels of concentration than sewerage.

CONCLUSIONS

In order to establish more effective control measures against hydrogen sulfide, it is imperative to expedite further investigations on the features of drainage from the fish-processing industry. It is essential to investigate to sort by type of industry, because of the different levels of H_2S generation. It is a very important subject for the management, staff working in the treatment facilities and those engaging in fish-processing industries. In addition, this research should contribute to water property conservation in the fishing ports as well as improve environmental sanitation.

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A STUDY ON ULTRAVIOLET SPECTRAL REFLECTANCE OF COASTAL SANDS

Toshimasa Kawanishi and Jesun Uh

College of Science and Technology, Nihon University
Funabashi, Chiba, Japan
kawanisi@ocean.cst.nihon-u.ac.jp

ABSTRACT

In the recent years, destruction of ozone layer by CFC has resulted in an increase in the amount of ultraviolet radiation reaching the earth surface. Especially, the effect of ultraviolet radiation in coastal zone is higher than that in inland area. These large amounts of ultraviolet radiation are capable of causing health problems involving the skin cancer and eye damage of people. The effect of ultraviolet radiation in coastal zones is higher than that in terrestrial zones due to the reflection from the sand surface. Spectrophotometer is used for the measurement of reflectance. The wavelength is divided into three regions: UV-C 240-280 nm, UV-B 280-315 nm and UV-A 315-400 nm, Visible 400-780 nm. Diameter of the integral sphere is 150 mm. This report shows measurements of ultraviolet spectral reflectance on the sands in order to investigate the relationship between reflectance and sand surface characteristic. From the measurement results, the ultraviolet reflectance on sand are about Visible 3% -59%, UV-A 3% -33%, UV-B 3% -19% and UV-C 2% -17%. The ultraviolet reflectance can be estimated by visible reflectance. As sand's lightness becomes higher, ultraviolet reflectance also becomes higher.

INTRODUCTION

The increase of ultraviolet radiation caused by the destruction of the ozone layer (Kaya et al., 1994) produces various health problems related to human bodies such as skin cancer and cataract (I.Thiyou. 1993). Along with the increase in outside activities, the number of people who work in a coastal zone is also increasing. Ultraviolet radiation has great effects on the people as well as the deterioration and discoloration of buildings. The ultraviolet reflectance of the coastal sand is one of the important factors of ultraviolet radiation in the coastal zone. As seen in figure 1, the ultraviolet reflectance from the coastal sand, which is located in front of coastal buildings, determines the amount of incident ultraviolet radiation to the buildings. Therefore, it is necessary to know the ultraviolet reflectance of coastal sands in order to control the ultraviolet radiation. The ultraviolet reflectance of various surfaces such as sand, snow and turf is measured by (K. Buttner.1935), (C. J. Kok and L. A. G. Monard.1986), (Fukuda.1987), and (M. Blumthaler and W. Ambach.1988). Also, (Kawanishi, et al.1995~7) have studied the relationship between the sand composition and reflectance, and proved that only surface characteristics are related to the ultraviolet reflectance. However, there is almost no research which reports the relationship between the reflectance and ultraviolet wavelength or the surface characteristics of coastal sands. As various researches in ultraviolet band region progress, there is a need for an average reflectance in different wavelength bands which corresponds to several kinds of phenomenon which occur at different wavelength ranges, red spots on a skin, and discoloration. In this research, the ultraviolet spectral reflectance of many kinds of coastal sand is measured, and their relationships with visible ray reflectance are discussed in different wavelength bands. Also, the relationships with the lightness, roughness, and chromaticity, which are surface characteristics, are discussed.

COASTAL SANDS

Gathering locations and kinds of sands

Samples coastal sands are taken from various places: 6 locations in Japan, 9 locations in Australia, 2 locations in Korea, 2 locations in Portugal, 1 location in France. Figure 2 shows the sampling places of the coastal sands. Sands are sampled about 10 to 20 m from the waterline. Figure 3 is the photograph of the coastal sand put in a 50 mm diameter sample tube with frame. Table 1 shows the mineral components ratio of the sand. In order to examine the mineral components of the sand, a scanning electron microscope (electric field discharge type) was used. To perform a composition analysis with the electron microscope, the sample was deposited with carbon in a vacuum using EPMA (Electron Probe Micro-Analyzer) before the analysis. The result of the composition analysis shows high Oxygen (O) content. Also, high values of Silicone (Si) and Calcium (Ca) indicate that the main ingredients of sand are considered to be QTZ (quartz) and shells.

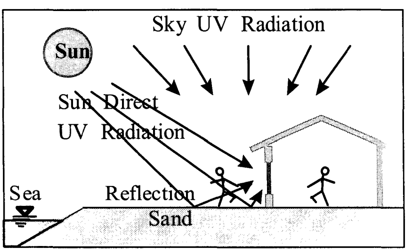

Figure 1. Ultraviolet radiation on coastal zone

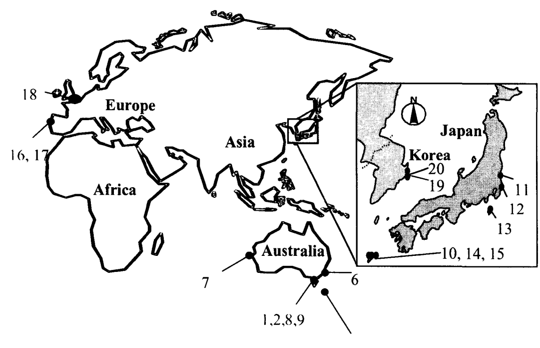

Figure2. Sampling places on coastal sand

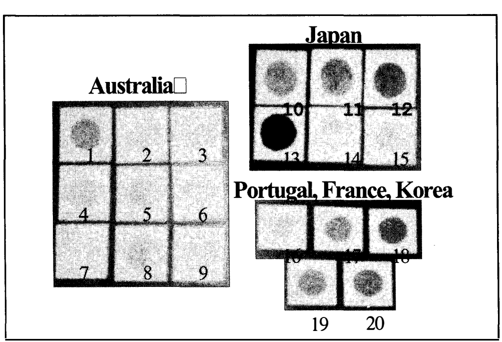

Figure 3. Kinds of coastal sand

Table 1. Components of coastal sand

No.	Sampling Place \ Item	Components (%)						
		O	Na	Mg	Al	Si	Ca	Fe
1	Australia Apollo Bay	58.0	1.16	1.07	1.35	36.5	1.50	0.50
2	Australia South Melbourne Beach	66.9	1.58	1.33	2.26	23.1	3.79	1.02
3	Australia Tasmania Bichen Beach	64.9	1.76	0.58	6.11	25.5	0.49	0.68
4	Australia Tasmania White Beach	66.5	4.63	2.74	1.56	3.21	20.5	0.87
5	Australia Tasmania RoarinBeach	64.9	5.76	2.48	1.52	3.14	21.4	0.86
6	Australia Port Cambell	65.8	4.40	2.10	1.55	8.02	17.5	0.60
7	Australia Perth	65.3	2.68	1.51	1.79	19.6	8.22	0.92
8	Australia Cowes Phillip	60.4	1.84	1.50	2.33	31.3	1.28	1.35
9	Australia Melbourne St.Kilda	62.1	1.77	1.10	1.53	31.4	1.27	0.85
10	Okinawa Yomitan	60.5	1.80	1.59	3.34	29.4	2.03	1.42
11	Takahagi	57.6	2.92	3.15	7.11	23.3	1.94	4.06
12	Kujukuri	57.9	3.35	2.54	6.45	24.6	1.90	3.26
13	Oshima	61.9	2.30	1.52	3.19	26.7	3.38	0.99
14	Okinawa Manza Beach	55.7	3.50	5.40	7.57	19.0	3.75	5.03
15	Okinawa Tinenn	72.3	2.19	3.10	1.15	1.01	19.7	0.55
16	Portugal Caskisa	70.3	1.90	3.23	1.20	1.09	21.5	0.75
17	Portugal Esutil	61.7	1.76	1.25	3.25	21.6	9.27	1.14
18	France Monsanmisell	60.9	2.54	1.41	1.64	26.7	5.84	1.00
19	Korea Kuananri	62.1	1.99	1.37	3.06	24.8	5.50	1.23
20	Korea heunde	62.8	2.55	1.76	3.36	14.6	13.1	1.75

COASTAL SAND AND SURFACE CHARACTERISTICS

Roughness measurement

Roughness is measured by. a surface roughness shape measuring equipment called SURFCOM, The central-line average roughness Ra is measured with the JIS B 0651 standard needle contact method.

Lightness and chromaticity measurement of the sample

Toshiba lightbulb-type fluorescent lamp EFT15EDG, which has the daylight color, is used because the light produced by the lamp is close to the standard light C, and the measurements are taken by a color-difference meter which uses the Yxy color coordinate system. A standard white-board for CR-231 was used for standard calibration. The measuring method of lightness and chromaticity complied with JIS Z 8722.

Measurement results

The measurement results are shown in table 2 using the symbol Ra for the surface roughness, L* for lightness, and Cx and Cy for the x and y axis chromaticity values of the CIE standard color coordinate system, respectively. The surface roughness Ra values were 23.7 - 60.1μm for the Australian sands, 29.2 - 55.6μm for the Japanese sands, 34.0 - 47.2μm for the Korean sands, 35.3 - 48.5μm for the Portuguese sands, and 44.9μm for the French sand. The sand with the lowest lightness L* came from Oshima, Japan and its value was 6.4%. The sand from Perth, Australia had the highest lightness of 86.2%. The ranges for the chromaticity Cx and Cy were 0.354 - 0.41 and 0.361 - 0.415, respectively.

Table 2. Surface characteristics of coastal sand

No.	Item / Material	Roughness Ra(μm)	Lightness L*(%)	Chromaticity C_x	C_y
1	Australia Apollo Bay	28.3	35.6	0.401	0.407
2	Australia South Melbourne Beach	60.1	55.5	0.399	0.408
3	Australia Tasmania Bichen Beach	42.6	62.0	0.366	0.389
4	Australia Tasmania White Beach	23.7	46.7	0.376	0.398
5	Australia Tasmania Roaring Beach	40.1	38.1	0.393	0.410
6	Australia Port Cambell	39.5	39.2	0.393	0.410
7	Australia Perth	39.7	86.2	0.384	0.397
8	Australia Cowes Phillip	50.5	46.6	0.422	0.415
9	Australia Melbourne St. Kilda	42.2	49.9	0.409	0.411
10	Okinawa Yomitan	29.2	58.4	0.393	0.403
11	Takahagi	46.7	36.4	0.392	0.411
12	Kujukuri	35.8	25.2	0.397	0.410
13	Oshima	51.8	6.4	0.354	0.361
14	Okinawa Manza Beach	55.6	68.2	0.388	0.400
15	Okinawa Tinenn	54.3	43.4	0.385	0.404
16	Portugal Caskisa	48.5	52.7	0.400	0.405
17	Portugal Esutil	35.3	46.3	0.410	0.406
18	France Monsanmisell	44.9	31.5	0.374	0.395
19	Korea Kuananri	47.2	32.0	0.388	0.405
20	Korea heunde	34.0	33.6	0.404	0.413

ULTRAVIOLET SPECTRUM REFLECTANCE MEASUREMENT

Measurement principle

For measuring the ultraviolet reflectance, one method is to use the ultraviolet radiation illuminometer to measure the radiation coming from above and below and calculate using these two values. However, a shortcoming of this method is that it cannot measure the reflectance for different wavelengths. Here, Shimazu UV-3100 spectrophotometer was used to take continuous measurement from ultraviolet band to visible ray band. For this research, in accordance with the CIE categorization (CIE. 1957), the ultraviolet band is categorized into short wavelength band UV-C (240 - 280 nm), medium wavelength band UV-B (280 - 315 nm), and long wavelength band UV-A (315 - 400 nm), and visible ray band is 400 - 780 nm. The inner radius of the spectrophotometer's integrating sphere, which was used in this research for taking measurements, was 150 mm ϕ and it can measure the spectral reflectance of the solid sample. Samples are 20 different kinds of coastal sand shown in table 1. Figure 4 shows the optical concept of reflection. The reflectance measurements were taken using following procedures. Before measuring the sample, the standard white-board made by $BaSO_4$ from Kodak Eastman Reagent was placed at the sample and reference side of the reflection sample position on the integration sphere and the equipment was adjusted for 100%. Next, the standard white-board at the sample side was replaced by the measuring sample, and reflectance spectrum for 240 - 780 nm was recorded. The measurements were taken every 5 nm and multiplied by the absolute reflectance of $BaSO_4$.

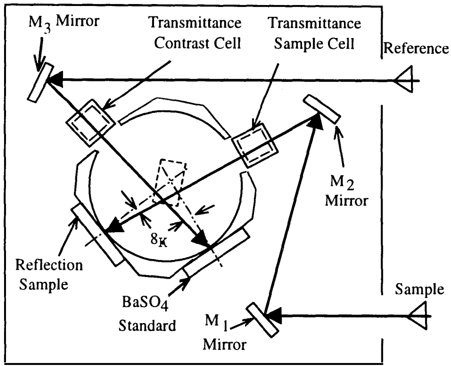

Figure 4. Measurement of reflectance

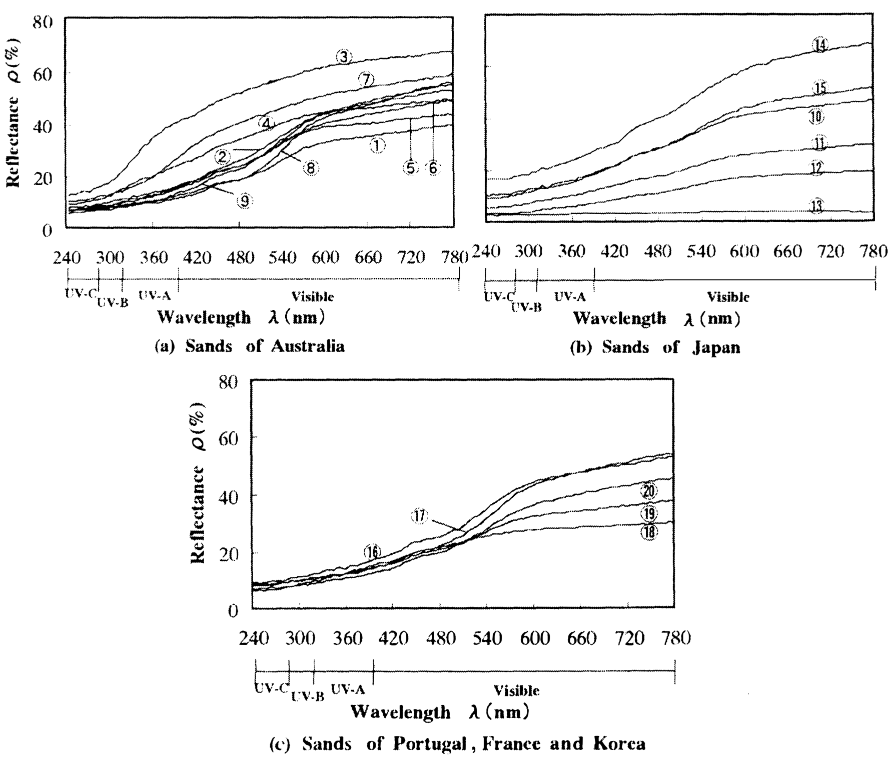

Figure 5. Reflectance for wavelength

Measurement results

Figure 5 shows the spectral reflectance of ultraviolet and visible ray. Of the 20 kinds of coastal sand, the reflectance of the sand from Tasmania Bichen beach and Perth, Australia show small changes until 320 nm, but increases gradually after 320 nm. Overall reflectance is high for all 9 kinds of Australian sand. Japanese coastal sands have different reflectance values which varies from low to high. The reflectance range of coastal sand from Oshima, Japan is 2% - 4% for all wavelengths, and is quite small. Sands from Portugal, France and Korea have small reflectance ranges in both the ultraviolet and visible ray band when compared with those of other country's sands.

Table 3 shows the average spectral reflectance of different bands, which are categorized into UV-C, UV-B, UV-A, and visible ray band. UV-C reflectance is expressed as ρc, UV-B reflectance is expressed asρb, and UV-A reflectance is expressed asρa, and visible ray band reflectance is expressed asρv. UV-C reflectanceρc range is 2.48% - 16.7%, UV-B reflectanceρb range is 2.59% - 18.5%, and UV-A reflectanceρa range is 2.97% - 32.6%, and visible ray band reflectance ρv range is 3.49% - 58.7%. The sand with the highest ultraviolet reflectance came from Okinawa Manza beach, Japan and had UV-B reflectanceρb of 18.5%. The lowest UV-C reflectanceρc came from the sand of Izu Oshima, Japan and was 2.59%. The separation between the two is more than sevenfold.

Table 3. Visible and UV reflectance

No.	Item / Material	Reflectance(%)			
		UV-C ρc	UV-B ρb	UV-A ρa	Visible ρv
1	Australia Apollo Bay	7.79	8.42	10.8	28.8
2	Australia South Melbourne Beach	7.86	9.19	13.0	39.4
3	Australia Tasmania Bichen Beach	13.8	17.6	32.6	58.7
4	Australia Tasmania White Beach	10.1	12.5	20.0	41.1
5	Australia Tasmania Roaring Beach	8.55	10.0	13.7	34.0
6	Australia Port Cambell	7.69	8.90	12.5	35.8
7	Australia Perth	11.1	12.8	20.0	48.1
8	Australia Cowes Phillip	7.30	8.07	10.2	36.3
9	Australia Melbourne St Kilda	6.49	7.50	10.7	37.7
10	Okinawa Yomitan	9.39	11.3	15.3	37.0
11	Takahagi	5.74	7.08	10.1	23.3
12	Kujukuri	3.29	3.86	5.87	15.2
13	Oshima	2.48	2.59	2.97	3.49
14	Okinawa Manza Beach	16.7	18.5	23.7	53.2
15	Okinawa Tinenn	10.6	12.3	16.1	39.3
16	Portugal Caskisa	9.58	11.1	14.6	38.6
17	Portugal Esutil	8.36	9.55	12.1	37.1
18	France Monsanmisell	6.85	8.48	12.5	25.5
19	Korea Kuananri	8.72	10.0	12.5	28.8
20	Korea heunde	7.48	8.40	10.8	31.8

Figure 6 shows correlations between the visible ray reflectance and ultraviolet reflectance. The correlation coefficient r for UV-A reflectanceρa is 0.886, the r for UV-B reflectanceρb is 0.912, and the r for UV-C reflectanceρc is 0.9, and these are all high values. The sand with high visible ray reflectance has high ultraviolet reflectance as well. Judging from the slope of a regression lines, UV-A reflectance is 0.47 times, UV-B reflectance is 0.28 times, and UV-C reflectance is 0.22 times the corresponding visible ray reflectance. Thus, if the visible ray reflectance is known, the approximate ultraviolet reflectance can be estimated by multiplying the visible ray reflectance by 1/4 to 1/2 for each wavelength band.

$$\rho a = 0.473\,\rho v - 2.21 \quad (r = 0.886) \tag{1}$$
$$\rho b = 0.288\,\rho v - 0.09 \quad (r = 0.912) \tag{2}$$
$$\rho c = 0.233\,\rho v - 0.42 \quad (r = 0.900) \tag{3}$$

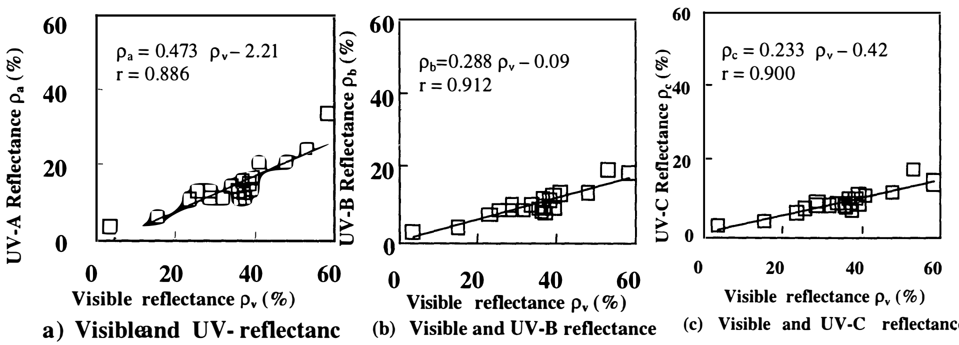

Figure 6. Relation between visible and UV reflectance

ULTRAVIOLET SPECTRAL REFLECTANCE AND SURFACE CHARACTERISTICS

Correlation function

The correlation coefficients r for the UV-C reflectanceρc, UV-B reflectanceρb, UV-A reflectanceρa, visible ray reflectanceρv, surface roughness Ra, lightness, L*, and chromaticity Cx and Cy were calculated to determine the cause of the increase in ultraviolet reflectance of the sand. Table 4 shows the correlation matrix. For the roughness, the correlation was small for each wavelength band. For the lightness L*, correlations were 0.765, 0.756, 0.700 for the ultraviolet reflectance and 0.872 for the visible ray reflectance, and all values were high. However, there were no apparent correlations between ultraviolet reflectance and the chromaticity Cx and Cy.

Table 4. Correlation matrix

	UV-C ρc	UV-B ρb	UV-A ρa	Visible ρv
Roughness Ra	0.110	0.060	0.000	0.033
Lightness L*	0.765	0.765	0.700	0.872
Chromaticity Cx	-0.092	-0.160	-0.281	0.134
Chromaticity Cy	0.054	0.020	-0.071	0.242

Ultraviolet spectral reflectance and roughness, chromaticity, lightness

Figure 7 shows the relationship between the UV-B reflectanceρb and the roughness Ra. Data points are scattered and no correlation can be seen. Figure 8 shows the relationship between the chromaticity Cx and UV-B reflectanceρb. Most of the sand chromaticity is gathered around 0.4. The chromaticity is limited to the natural color of the sand and there is no trend related to the reflectance. Figure 9 shows the relationship between the reflectance and the lightness of the sand. Most of the coastal sand lightness are found around the 30% - 60% region, and when the lightness increases, ultraviolet reflectances increases in all UV-A, UV-B, and UV-C bands.

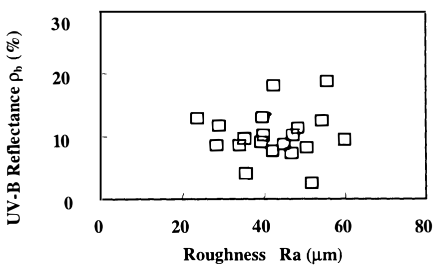

Figure 7. Relation between UV-B reflectance and roughness

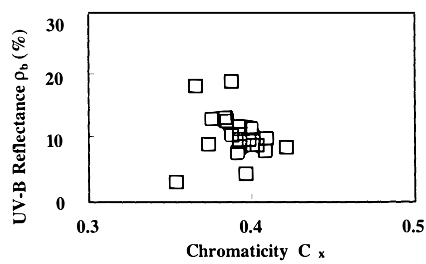

Figure 8. Relation between UV-B reflectance and chromaticity

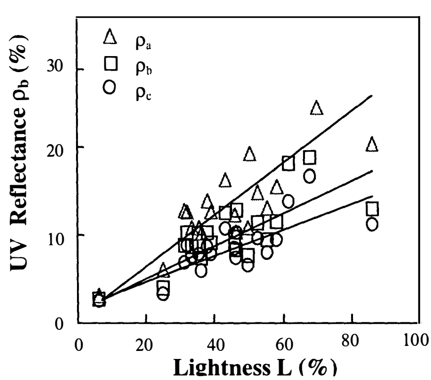

Figure 9. Relation between reflectance and lightness

CONCLUSIONS

The ranges of average reflectances of the coastal sand, which are caused by the ultraviolet radiation, are 2.48% - 16.7% for the UV-C, 2.59% - 18.5% for the UV-B, 2.97% - 32.6% for the UV-A, and 3.49% - 58.7% for the visible ray.

The visible ray reflectance is strongly correlated to the ultraviolet reflectance. Judging from the slope of regression lines of visible ray reflectance on ultraviolet reflectance, UV-A reflectance is 0.47 times, UV-B reflectance is 0.28 times, and UV-C reflectance is 0.22 times the corresponding visible ray reflectance.

The ultraviolet reflectance of the sand has strong correlation with the lightness and when the lightness increases, the ultraviolet reflectance increases.

When constructing buildings in a coastal area, there are natural sands or artificial sands in the area. These sands determine the quality of the area in terms of the effects on the human health. In order to reduce the effect of ultraviolet radiation, it is required to select the coastal sand with low reflectance. To protect human skins, it is necessary to use the coastal sand with low UV-B,UV-A reflectance. To deal with material deterioration, it is necessary to use the coastal sand with low UV-A reflectance.

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UTILIZATION OF SUN GLITTER IN COASTAL ZONE

Toshimasa Kawanishi and Hiroo Nakanishi

College of Science and Technology , Nihon University
Funabashi, Chiba, JAPAN
kawanisi@ocean.cst.nihon-u.ac.jp

ABSTRACT

Sun-glitter is the reflection of the setting sun on the surface of the sea. Sun-glitter covers a wide area of the sea while the sun is high, but narrows to a single golden bar as the sun sets. The reflection is constantly scattered and refracted by the waves, producing an exceptionally attractive pattern that should be considered a major scenic resource. This research examines the physical characteristics of sun-glitter, and demonstrated that sun-glitter exerts a powerful emotional and physiological effect on humans. This research focuses on utilization of sun-glitter as a scenic resource in design of coastal facilities. Field research was conducted along the coast of the Sea of Japan, where coastal architecture has been designed to take advantage of sun-glitter, and comparisons were made with idealized images of sun-glitter.

INTRODUCTION

When rays of sunlight are reflected directly off the sea surface, the resulting visual phenomenon is called "Sun-glitter". Sun-glitter has been referred to poetically as "The Road to Happiness" and "The Golden Bridge", and is frequently employed to produce a romantic or artistic effect in photographs and movie scenes. In this manner, sun-glitter is thus a major scenic resource in coastal environments (Enomoto, 1986; Kawanishi, 1994; Fujie, 1993). Fig.1 shows typical coastal sun-glitter . This study indicates sun-glitter color change clearly in numerical values. It also studies the relationship between the psychological and physiological influences of the visual environment on human beings and the physical quantity of sun-glitter. Influences on psychology, human behavior, and the visual environment are investigated from the aspect of Between Comfort and Discomfort (BCD), and the delay in pupil contraction respectively (Ogura, 1996). The results of these investigations are summarized in a sun-glitter classification table to define what is attractive sun-glitter. In addition, the time zone of sun-glitter in each scale that varies day by day is shown schematically for quick reference of people visiting the coast.

The physical characteristics

The research was implemented at Makuhari Beach located in Chiba Prefecture, along the northern shore of Tokyo Bay, Japan. The location of the research site is shown in Fig.2. Three physical variables namely sun-glitter, luminance, chromaticity and sea surface illumination, were measured for a total of 49 days between June, 1990 and January, 1995. Measurements were taken at 5° intervals from zenith to 35°, at 3° intervals from 35° to 14°, and 2° intervals from 14° to sunset. The data obtained on fine days is used to prepare the classification table.

Figure 1. Sun-glitter

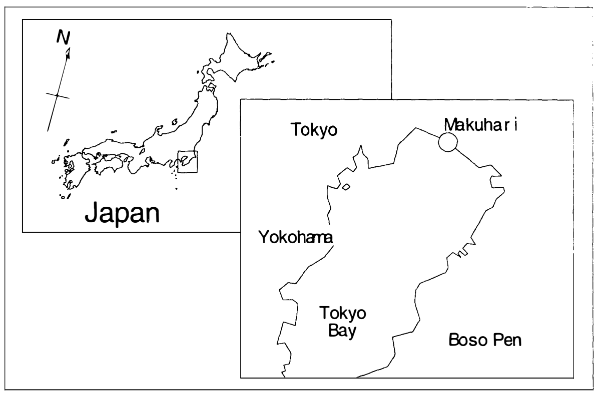


Figure 1. Research site

Measuring method

The chromaticity of sun-glitter is the numerical indication of sun-glitter color changing in a day. Luminance of the sun-glitter was measured with a luminance meter (MINOLTA LS-100), and the maximum values were recorded. Chromaticity was measured with a chromaticity meter (MINOLTA CS-100), and the value occurring at maximum luminance was recorded. Sea surface illumination was measured with an illuminance meter (MINOLTA T-1) stood vertical and pointed directly at the sea surface. A horizontal shade (30×45cm) was attached to the sensor to screen out direct rays and light diffused in the air. The measurement system is shown in Fig.3. A total of 491 measurements were obtained for each of the three variables, but only data obtained under condition of cloud density of 1-3 and level 0-1 on the wind scale were utilized in the analyses.

Measurement results

Sun-glitter chromaticity

The relationship between sun-glitter color and the sun's elevation is shown in Fig.4. X axis is the color change. Y axis is the sun's elevation. From the measurement results, sun-glitter color changes in the order of white color, pale yellow, pale orange, orange, and red as the sun's elevation decreases from around noon to sunset. It was found that the sun-glitter turns red just before sunset.

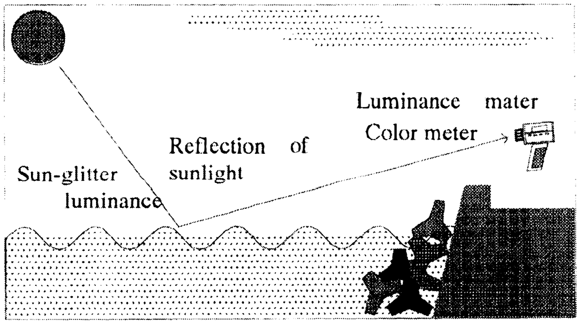
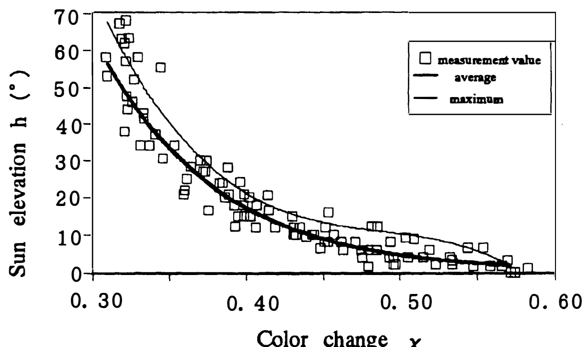


Figure 3. Measurement System



White	pale yellow	pale orange	orange	red

Figure 4. Sun-glitter Color Change

Sun-glitter luminance

The relationship between luminance and sun elevation is shown in this Fig 5. The Y axis means sun-glitter luminance. The X axis means sun elevation. It can be seen that luminance increases as the sun sets, and reaches a peak at an elevation of 8 degrees, and it goes down. Sun-glitter luminance changes like this in a day. Luminance increases as the sun sets and

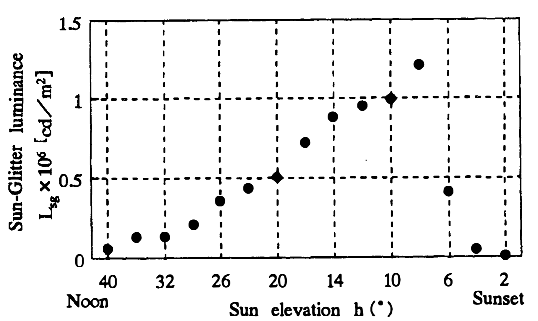


Figure 5. The Changes of Luminance of Sun-Glitter

reaches its peak with the colors pale yellow and pale orange. It is found that luminance degreases suddenly when the sun is about to set.

PSYCHOLOGICAL EVALUATION

Study on BCD

When luminance in the field of vision is increased gradually and exceeds a certain limit, it makes people uncomfortable. Obtaining this limit by changing the apparent size of the light source and brightness in the surrounding area allows us to find the border line between comfort and discomfort. This border line is called Between Comfort and Discomfort (BCD), which is used as an index for evaluating the light source. For 15 days from August 1990 to December 1991, a survey was conducted at Makuhari Beach. The SD Questionnaire Method containing 16 items to be evaluated on seven ranks, was used and the subjects included seven students from our College. As a result, psychological structures were obtained, for example, "Sun-glitter colors, red, in particular have a favorable influence on psychology" and "Sun-glitter colors are very dazzling when they are white, pale yellow, and pale orange." In this report, sun-glitter colors and luminance were used as evaluation conditions while comfort, dazzle, beauty, and peacefulness were used as evaluating items. Figures 6, 7, 8, and 9 show BCD for individual items.

Comfort

As shown in Figure 6, sun-glitter is felt to be uncomfortable at a luminance of approx. 3×10^3 to 10^5cd/m^2 or higher in white and approx. 10^5 to 10^6 cd/m^2 or higher in pale yellow. That is, it is felt uncomfortable at a luminance of 10^6 cd/m^2 or higher. Sun-glitter is always felt to be comfortable when it is orange or red. Sun-glitter has a long and narrow shape.

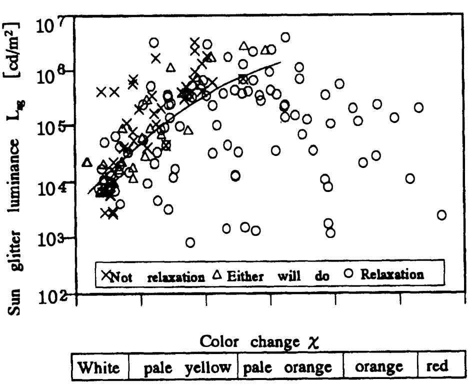


Figure 6. Sun-glitter Luminance and Relaxation

Dazzle

As shown in Figure 7, sun-glitter is felt to be dazzling at a luminance of approx. 4×10^3 to 3×10^4 cd/m^2 or higher in white, approx. 3×10^4 to 1×10^6cd/m^2 or higher in pale orange and orange, and 10^5cd/m^2 or higher in red. Sun-glitter basically has a thick shape.

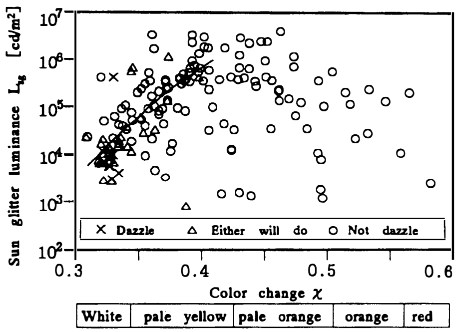


Figure 7. Sun-glitter Luminance and Dazzle

Beauty

Figure 8 shows beauty. Sun-glitter is felt to be beautiful in every color, regardless of color changes. Sun-glitter evaluated as beautiful has a long and narrow shape just before sunset.

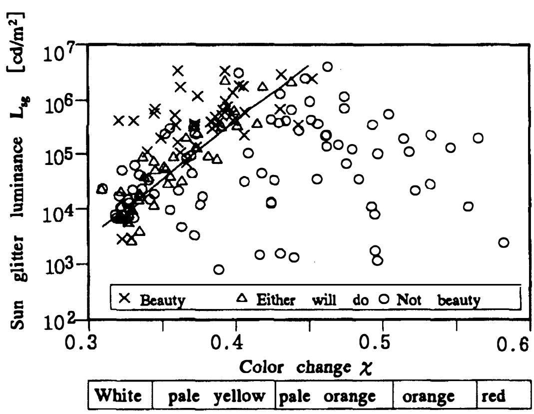


Figure 8. Sun-glitter Luminance and Beauty

Peacefulness

Figure 9 shows peacefulness. Sun-glitter is felt to be peaceful at a luminance of approx. 3×10^3 to 10^5 cd/m^2 or lower in white, approx. 10^5 to 10^6 cd/m^2 or lower in pale yellow, and 10^6cd/m^2 or lower in pale orange. When sun-glitter is orange or red, it always is peaceful, regardless of luminance. Sun-glitter has a somewhat long and narrow shape when in orange and red.

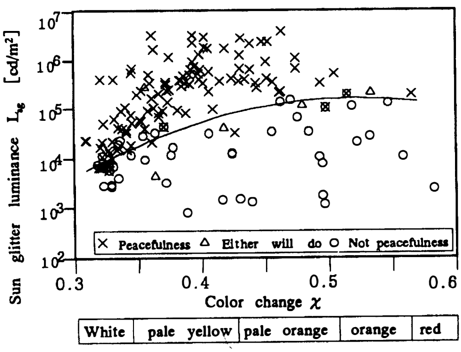


Figure 9. Sun-glitter Luminance and Peacefulness

PHYSIOLOGICAL EVALUATION

Research method

We used an eye-test chart to clarify the influence of sun-glitter on the sense of sight. This device makes use of pupil contraction called shading to determine to what extent adjustment is degraded due to the presence of sun-glitter in the field of vision. If there is a delay in pupil contraction, it means that the adjustment is degraded and the sense of sight is interfered from sun-glitter. Our experiment was conducted at Makuhari Beach, or four days on November 4 and 5, 1991 and December 7 and 14, 1991. The subjects included seven students from our College who had vision of 1.0 or better on the Japanese eye examination scale. Using the eye-test chart, we tested the eyesight of the subjects in a room immediately after watching sun-glitter to evaluate the degree of degradation in their sight. Delay in pupil contraction is defined as the time ratio a person spent gazing at sun-glitter to the degradation degree in sight. It is expressed as follows: Delay in pupil contraction =

Watching time obtained in the experiment / Individual indoor reference time.

Trend of delay in pupil contractions

Figure 10 shows the relationship between the delay in pupil contractions and the sun-glitter color. The delay in pupil contraction increases as the sun sets. It reaches a peak when the sun-glitter is pale yellow and pale orange, and then goes down sharply to zero when the sun-glitter is red. That is, sun-glitter causes visual fatigue in human from the daytime until evening, and loses its influence at sunset.

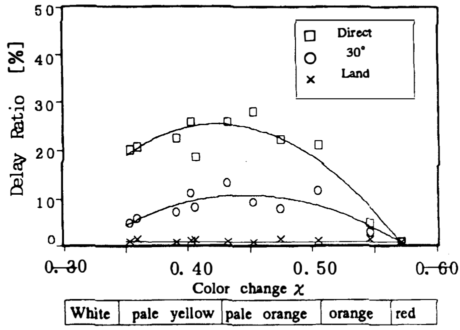


Figure 10. Delay Ratio

SUN-GLITTER CLASSIFICATION CHART

Table 1 shows sun-glitter classification chart. From the results as mentioned above, we divided sun-glitter into five scales depending on the color; Scale 5 is white, Scale 4 is pale yellow, Scale 3 is pale orange, Scale 2 is orange, and Scale 1 is red. Table 1 shows the relationship of the sun's elevation, sun-glitter luminance, typical shapes, BCD, and the delay in pupil contractions. The sun's elevation was calculated from the date and time. To obtain reliable data, we took the average of the sun's elevation in each scale. Shapes were classified based on conventional research. By classifying sun-glitter into five scales, we clarified the following characteristics.

1) Scale 5
Sun-glitter is white, it has an irregular shape and lasts the longest time during the day. From the aspect of BCD, higher luminance causes discomfort.

2) Scale 4
Sun-glitter is pale yellow. Dispersed sun-glitter comes in toward the center line. Both luminance and delay in pupil contractions are high.

3) Scale 3
Sun-glitter is pale orange, has the highest luminance and delay in pupil contractions and is the most unfavorable to human sight.

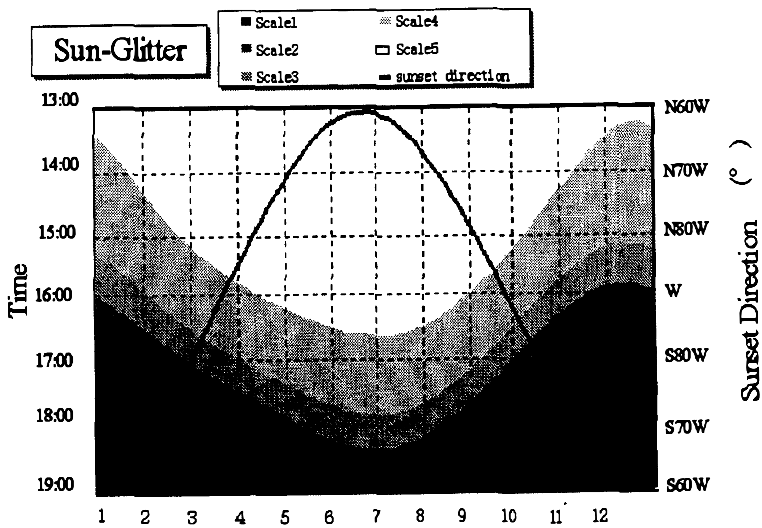
4) Scale 2
Sun-glitter is orange and can be seen just before sunset. People always feel comfortable at this time because both luminance and delay in pupil contractions are decreased.

5) Scale 1
Sun-glitter color is red, dark, unclear and causes no delay in pupil contractions. People feel comfortable at this time although it is rarely recognizable.

SUN-GLITTER CHART

Based on the sun's elevation in each scale of the sun-glitter classification table we calculated the time when sun-glitter occurs in each scale, in a year. Figure 11 is the sun-glitter chart.

This chart tells you when you can observe comfortable sun-glitter on a particular day. Sunset direction is also shown in a graph. Y axis means time. X axis means month. Sun-glitter has five colors. Scale 1 is red. You can feel relaxation. Scale 2 is orange. You can feel comfortable. Scale3 is pale orange. It is glaring. Scale4 is pale yellow. It is glaring too. Scale 5 is white. This line is sunset direction. For example when we would like to see this comfortable sun-glitter in a day Tokyo Japan, we put the date on month axis June 15 and adjust it on the orange part and confirm the six forty on the time axis. And the sun sets into west by the angle of 60 degrees from north.



Tokyo:+0' Hakodate:-22' Kobe: +22' Fukuoka: +39'

CONCLUSION

1) Sun-glitter color and form changes five variations.

2) According to the result of the questionnaires, human beings feel comfortable to have the orange, long and narrow shaped sun-glitter.

3) Sun-glitter chart was made by the date.
4) The rate of looking at sun-glitter increases in the lower scales.

5) Luminance and delay in pupil contractions are high in Scales 3 to 5, reaching a peak in Scale 3.

6) Sun-glitter is considered to be attractive, regardless of the scale and becomes more attractive in the lower scales.

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MANAGEMENT OF DEMOGRAPHIC AND ENVIRONMENTAL PRESSURES ON TORRES STRAIT ISLANDS, AUSTRALIA

David Hopley and Cecily Rasmussen

Coastal and Marine Consultancies Pty. Ltd.
Townsville, Queensland, Australia.
David.Hopley@ultra.net.au

ABSTRACT

The problems of increased population pressures on the reef islands of central Torres Strait are being aggravated by significant beach erosion. Two of the islands, Coconut and Sue, are examined to determine the scale of change and the causes. The islands are at a delicate geomorphological stage which is being pushed towards negative sediment budgets by changes to weather patterns and by anthropogenic inputs. The problem is serious enough to warrant greater management awareness and attention.

INTRODUCTION

Torres Strait, the shallow 150km stretch of water between north-eastern Australia and Papua New Guinea, formed a land bridge between the two land masses until as recently as 7500 yrs ago when the final phase of the post glacial transgression brought the present geography into existence, (Walker, 1972).

There are over 150 islands in these waters but only 18 are populated (fig. 1). The majority are forested high continental islands, but close to the New Guinea coastline are a number of low swampy islands formed from the abundant river sediments of the large Fly River deposited on older reef platforms. Even more remarkably some 4 vegetated coral cays in the middle of the Strait have villages each supporting permanent populations of between 130 and 300 people.

The islands in the Torres Strait were first inhabited approximately 700-800 yrs BP (Rowland, 1985). The reef islands, probably formed about 5000 yrs BP, are generally inhospitable with no permanent water, poor soils and limited vegetation resources, and were settled only intermittently at first as stopovers along important canoe trading routes. That they became permanently settled is a reflection of the economic and cultural importance of the marine environment to the Torres Strait Islanders, (Torres Strait Islanders have the highest seafood consumption per capita in the world, Johannes and MacFarlane, 1991), and the pressures and tensions on other islands.

The total population of the Torres Strait islands at the time of first European contact was about 4000 (Beckett, 1972). Today the total population is about 6000. In pre-European days, population was managed by traditional practices and migration to other islands. In the last 100 years the Torres Strait population has been maintained at a reasonably steady level by migration south to the mainland to the extent that some 15,000 people who identify themselves as Torres Strait Islanders now live on mainland Australia (Arthur, 1991). However, in more recent times, the islands have become more prosperous not only through direct Government agency support but also with the expansion of the crayfish export industry

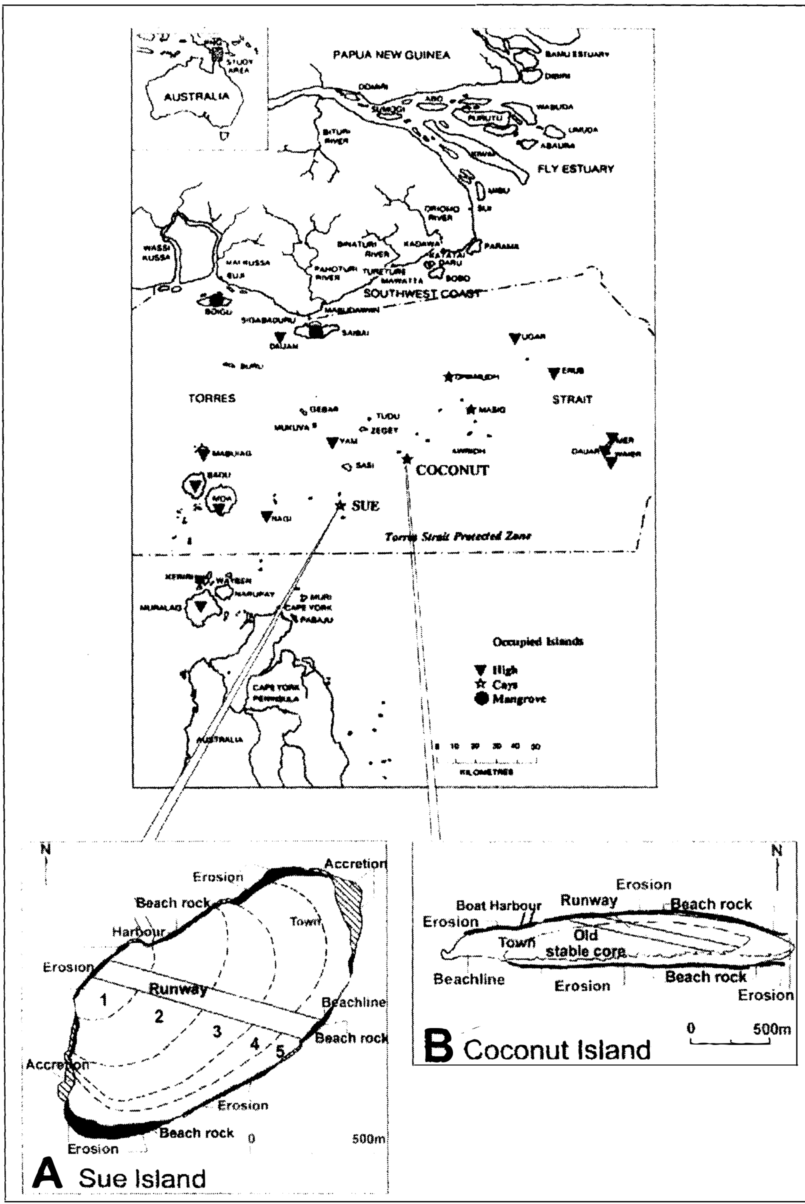

Fig. 1 Torres Strait Region with Traditionally Occupied Islands. A. Sue Is. B. Coconut Is.

worth almost a $4 million annually (Arthur, 1991). Also in 1985 as part of the Torres StraitTreaty with Papua New Guinea the Torres Strait Protected Zone was established to maintain the traditional way of life and livelihood of the Islanders. Recognising the then low standards of infrastructure on islands, in 1988 the Minister for Aboriginal Affairs released the 'Priority Community Development Strategy for Torres Strait', with a $23 million spent over a 3 year period. In addition there was also considerable expenditure and employment created within the Commonwealth Government's Development Employment Projects Scheme.

The end result is that there is now a "small but noticeable flow of Islanders returning to the islands" (Arthur, 1991) as the quality of life has improved with better communications (almost every island has jetty and aircraft landing facilities), permanent water storage and electricity from generators. There are also more employment opportunities. But this is putting renewed pressure on limited land resources of both high and low islands. On the low coral islands the dilemma is being seriously aggravated by beach erosion which is reducing the useable areas especially as older parts with garden soils are lost. Global warming and the high probability of sea level rise has been recognised by the islanders as having potential to exacerbate these problems.

We have examined two of the islands, Coconut and Sue to determine the pattern of erosion from previous surveys, aerial photographs and a 12 month monitoring programme. Causes and mechanisms are recognised and various solutions considered. Results may be applicable to other small tropical islands for which similar problems have been recognised (e.g. Maul, 1996).

CASE STUDIES

Environment

Located between 9^0 and 10^0 south of the equator the Torres Strait islands are subjected to a strong seasonality in climate with a wet summer monsoonal period between December and March dominated by light to moderate north-westerly winds contrasting with the remainder of the year when drier and stronger (25kn) south-easterlies prevail though still with possibilities of rainfall. Annual rainfall totals are approximately 1600mm. Tropical cyclones at this low latitude are rare but storms in the Coral Sea can generate large waves which can affect the Torres Strait islands.

Tides of the region are complex being influenced by the semidiurnal tidal regimes of the Coral Sea and diurnal tides of the Arafura Sea. Maximum Spring range is about 3.5m. Tidal currents can be extremely strong and are predominantly diurnal.

Coconut (Poruma) Island (fig. 1 B)

Coconut Island, approximately 1.9km long and 300m wide, is situated on the north-western side of a high sanded reef about 6km in an east-west direction and 2km wide. Island area is about $0.44km^2$ and the total volume of sand estimated at 1.7million m^3.

Approximately two thirds of Coconut Island appears to be a relatively old and stable core with elevation of c. 5m above Mean High Water Springs (MHWS). This area has garden soils and originally a mature forest vegetation, though most of this is cleared. More recent additions to the island occur as spits at both eastern and western ends, characterised by raw carbonate sands with little or no soil development. A most distinctive and unusual feature on Coconut Island is the suite of dunes rising to 10m above MHWS along the south coast. They are clearly mobilised by the strong south-easterly winds and have numerous active blowouts. They form a very effective shelter for the island from the strong south-easterlies. Beachrock is found in a band up to 20m wide around almost the entire island. Beach recession of up to 25m is indicated along the entire southern side, and perhaps 10m along much of the northern side. There are at least 3 generations of beachrock, suggesting a long history of erosion and progradation, and some change in island orientation.

The geomorphology and shape of Coconut Island clearly suggests instability (Hopley, 1982, 1997a). The dynamics of the island could not be confirmed from the limited and poor quality aerial photography available, apart from rapid changes to the spits, particularly at the western end of the island. The addition of a beach ridge on the southern side (now part of the dunes) is reported to have prograded the coastline by up to 20m over the last 25 years but a net loss of land around the entire island has been a more recent trend.

In the absence of quantitative data, a monitoring programme, designed by the authors and instigated by consulting engineers Edmiston and Taylor of Cairns, was carried out between September 1996 and September 1997. 21 beach profiles about 200m apart were monitored every 2 months (7 surveys) and have provided a detailed account of an annual cycle (Hopley and Rasmussen, 1998). Sand budgets were calculated for the profile results and extrapolated either side by incorporating the distance between stations. The major conclusions were:

1. Rapid changes occur around the spits, net erosion on the north-western side of the island, and to a lesser extent along the southern shore, and net stability or even gain along the north-eastern shore.

2. Nearly all the erosion took place in a short period in early summer during the onset of the north-westerly monsoon. Over 43,000m^3 of sand may have been removed from the beaches during this period. Spring tides and heavy rainfall appeared to accelerate this erosion. However, most of this sand appears to be retained on the adjacent reef flat during the sumer months.

3. In contrast, net annual loss of sand from the reef and island system appears to take place during winter when sand previously deposited on the reef flat is most mobile, rebuilding the beaches, but also with a proportion being pushed off the reef flat into deeper water.

4. A net loss of almost 20,000m^3 of sand from the beaches was recorded over the 12 months, representing more than 1% of the total sand store of the island, a pattern which may be an annual occurrence.

5. Exposure of massive beachrock and coarse reef flat rubble across the beach suggests even greater loss of sand over recent decades. The beachrock is now slowing down the rates of sand loss.

Sue (Warraber) Island. (fig. 1 A)

Sue is located on the north-western side of an oval reef about 5.5km in diameter. The island itself is also oval, about 1400 x 750m in size, and appears to have developed in 5 major stages, with each stage interspersed with numerous minor periods of progradation or recession. The oldest stable section of the island is the north-western corner. The second and third stages progressed towards the south-east, the fourth to the east and the fifth, most recent progradation has been to the east-south-east.

The highest elevations on the island (approximately 9m above MHWS) are in the third section. Sections 1, 2 and 3 (approximately two-thirds of the island) form a relatively old and stable core. The area is noticeable for its mature vegetation on soils with organic staining to approximately 40cm. A thick layer of pumice is present throughout this section at a depth of about 20cm. Section 4 is a comparatively recent addition to the island and is marked by a maturing soil profile with organic staining to around 20cm (slightly more in some areas) and a stable, maturing vegetation. The Sue Island township is located on the eastern end of this section. Section 5 has minimal soil development and the vegetation is almost entirely pioneering strand species.

Progradation has been in the form of a series of concentric beach ridges generally conforming to the shape of the island, and rising to heights of around 7m above MHWS on the eastern end. A largely submerged extension of the eastern spit extends across the reef flat off the north-eastern side of Sue Island. It appears to be highly mobile and a relatively recent formation. On this northern side of the island at least 5 generations of beachrock are present, further confirming intermittent oscillation of the beach and relating to the 5 stages of island development.

Erosion problems have been reviewed by Rasmussen and Hopley (1995). Aerial photographs were examined for the years 1966, 1974, 1978, 1977, 1981 and 1987 and further photography was undertaken over the island during this project in 1995. Changes were also discussed with the island elders. The gross changes are shown in figure 1, but can be summarised in 5 broad sectors:

i) Northern shore: recession over the last 30 years has been limited by extensive beachrock outcrops, more of which has become exposed as the last vestiges of beach sand have been removed.

ii) North-eastern shore: this includes the area in front of the township and is of considerable importance to the social life of the community. Major erosion has occurred here (especially between 1975 and 1977) with up to 40m of recession over the last 30 years in spite of reclamation and protection works.

iii) Eastern shore: movement of sand in both directions is indicated in this area of the eastern spit of the island, though the net movement of sand appears to be towards the south and onto the reef flat between 1966 and 1995. Progradation of about 60m is indicated in the 30 year period.

iv) Southern shore: this area was stable until about 1977 since when some 10m of erosion has taken place.

v) South-western and western shore: This includes the western spit of the island with sand moving northwards between 1966 and 1987. Erosion around the western spit is of the order of 60m over the 30 year period.

The conclusion drawn from the aerial photography was that over the last 30 years the island has pivoted in a clockwise direction but may not have had a major net loss of sand over this period, more a redistribution of sediments which is decreasing the area of older garden soils, and increasing the areas which lack soil development.

Seasonal patterns were observed. During the winter south-easterly season sand moves from the south-eastern corner of the island both westwards along the southern beach and northwards around the eastern end of the island. During the summer north-westerly monsoon season, sand moves around the western end in a southerly direction and along the northern coastline in front of the beachrock.

CAUSES OF BEACH CHANGES

Reasons for the beach recession observed on Coconut and Sue Islands (and reported on other Torres Strait reef islands) were sought in the long term geological record, shorter term changes to weather patterns and from human activities, all of which have been shown to have strong influences on coral cays.

Long term geological scale causes

Changes to coral reef carbonate sediment productivity and transport occur over time (Hopley 1997a). Accumulation of sediments to form cays during the Holocene appears to have occurred shortly after the first reef flats formed in response to a stabilising sea level, perhaps 5000 years ago. However, over time high productivity resulting from prolific coral cover is reduced as the reef flat matures and becomes sediment covered. Paradoxically, whilst abundant sediment may still be available on the reef flat, less of it is transported to the cay as reef flat height now determines that water cover is restricted to perhaps only 55% of each tidal cycle and even then the transporting power of the transmitted wave over the reef flat is drastically reduced. Nonetheless, whilst the cay is being starved of sand, high energy low frequency events may still erode the cay beach resulting in a negative sediment budget at the senile reef flat stage (Hopley, 1982).

This senile stage is being reached on Torres Strait reefs which have been at sea level for at least 5000 years. Reef flats which are heavily covered by sediment are exposed for about 4 hours on most low tides. Reef flats on both Coconut and Sue Islands are only just below mean sea level and wave energy is so attenuated on the cay beaches that along the exposed southern beach of Coconut Island, young mangroves are becoming established. Both flats are partially covered by seagrass and this too helps to retain sediment by the binding and baffling effects of roots and blades. At best the cays are in a stage of neutral sediment budgets and relatively small changes to the system can push them into a negative phase.

Medium t erm weather changes

Changes to coral cays as the result of changing weather patterns have been recognised both in Indonesia (Verstappen, 1954) and on the Great Barrier Reef (Flood, 1986). Absolute stability of a reef island will take place only when loss of sediment matches supply and the transporting media of wind driven waves and tidal currents remains constant through time. This rarely happens on any reef and thus constant changes take place on reef islands. Changes in weather may change the focal point to which the centripetal action of waves carries material. Reorientation of the cay will take place with erosion in some places and deposition in others. Examination of wind patterns may thus provide an indication of the cause of change.

Analysis of the wind records from Thursday Island in the southern Strait (and the only station available with long term records) between 1951 and 1992 indicates that the winter wind pattern has shifted to a more southerly direction over the last twenty years. (Detailed analysis of the wind records occurs in Rasmussen and Hopley, 1995). Examination of the records for each wind direction indicates that, of the more prevailing wind directions, the pattern for the summer north-westerly season has changed little over the period. However, there has been a statistically significant increase in winter winds from the south-south-east (of about 4% between 1950 and 1990).Combined with a statistically significant increase in wind speeds above 25km.h^{-1} during the winter period (from 17% to ca. 31% of the time) this is considered to have slowly realigned Sue Island in a clockwise direction. The change appears to have been fairly sharp and analysis of variance suggests that this took place somewhere between 1975 and 1977 with a fairly rapid shift in the intensity and duration of the winds from the south-south-east that has continued on to the present time.

This change in wind direction has led to a change in the pattern of wave refraction on the reef top and subsequent realignment of cays as sand is moved from one section of the island and redeposited in another. The pattern of change reported for Sue Island in particular is consistent with these weather changes but other cays in Torres Strait may also have responded in a similar manner.

Short term anthropogenic effects

Both Coconut and Sue Islands were examined to see if any human activities were influencing the observed erosion patterns. A number of factors were identified which, although common to both islands, had different degrees of importance:

1. Boat harbours and associated training walls:
As part of the development strategies for Torres Strait in the late 1980s both Coconut and Sue Islands were provided with boat harbours excavated from the reef flat, with channels 4m deep connecting them to the reef edge. Excavated materials have been used to create substantial breakwater walls and a loading ramp on Coconut Island and lower detrital banks on Sue Island.

On Coconut the harbour is on the north-western side and clearly has a groyne effect. During south-easterly and easterly (winter) weather there is significant sand build up on the eastern side and depletion to the west. During the north-westerly monsoon there is no complementary build up on the western side, but erosion to the east is experienced. Sediment is being directed into deeper water by the harbour walls from where it may be lost from the island system completely. There is very little sand size sediment remaining on the north-western beach, which is now largely beachrock and rubble.

On Sue the harbour is also on the north-western side of the island, deliberately located on one of the more stable parts of the island by the consulting engineers. The low walls are less of a barrier and although it does direct some sand out onto the reef flat from both westerly and easterly directions, and there has been some 0.5m of infilling of the channel since 1991, the impact on the adjacent coastline appears minimal.

2. Rock walls:
On both islands, some of the excavated material has been used to form rock walls in front of critical areas including in front of the community centre on Sue, and at the northern end of the aircraft runway on Coconut Island. Increased wave reflection against both these walls occurs at high tide and is contributing to loss of sand to the reef flat. On Sue the straight alignment of the wall (as opposed to a curved design which would both mimic and continue the line of the adjacent beachrock) is aggravating the problem. On Coconut 22.5m^3 of sand per linear metre of beach front was removed from the station in front of the wall during the summer monsoonal season with a net annual loss of 2.9m^3. In comparison a summer season loss of 12.1m^3 and a net annual gain of 8.8m^3 was recorded at the adjacent station which was not 'protected' by a wall.

3. Aircraft runways:
90m swathes are cut across both islands with runways taking up a considerable proportion of the older more stable parts. Runways *per se* are aligned parallel to the predominant winds (north-west, south-east) and the cleared land may be allowing a stronger air flow with some signs of enhanced dune erosion on the southern side of Sue Island, with a loss of wind blown sand out to sea off the northern shore.

4. *Ad hoc* protection measures:
On both islands, individuals have used *ad hoc* materials such as unconsolidated rubble, rubbish or, in particular, large used motor vehicle tyres to provide protection to the eroding upper beach. Many of these measures appear to be aggravating erosion problems, causing headland effects with scouring adjacent to or behind the barrier.

5. Vegetation damage:
At a number of locations damage to foredune vegetation by foot or vehicular traffic is encouraging the formation of dune blow-outs, especially in the large dunes of the southern coasts of both Sue and Coconut Islands. On Coconut a "Coastcare" (government funded) dune and vegetation restoration project has been attempted with limited success. Fresh blow-outs transgress the older more valuable garden soils.

DISCUSSION AND CONCLUSIONS

The populated coral cays of Torres Strait are at a vulnerable stage of geomorphological development which at best is providing a neutral sediment budget, and very little adaptability to further environmental changes. On Sue, an essentially stable, oval island, the volatility has come from medium term weather changes which are not so much reducing the size of the island or its sediment store, as reorientating it in a way which is increasing the area of young sand deposits at the expense of the older most useful parts of the island. On the more elongated and potentially unstable Coconut Island, changing weather patterns have had an effect mainly on the already volatile eastern and western spits. However, the new harbour has had a detrimental effect on overall sediment budgets to the extent that during 1996-97 a 1% reduction in the total sand store of the island occurred. This was in spite of up to 75% of the island's beaches being armoured with beachrock, the result of prior unquantified erosion which possibly resulted in an estimated loss of up to 3% of the island's sand over the previous 5 years. Other islands of Torres Strait have also reported beach erosion and the problem is widespread on other Great Barrier Reef islands and elsewhere.

In Torres Strait solutions to these problems need to be found on the islands themselves as renewed migration to other islands is now limited by availability, environmental considerations and the inertia effect of considerable recent capital expenditure on the infrastructure of the presently occupied cays. Ironically, some of the infrastructure which has helped attract population back to the islands, is aggravating the erosion problems.

Various solutions have been considered. Integrated management strategies, not just development, are needed which include both the introduction of commonly accepted beach and dune management projects, incorporating revegetation and, in the light of the limited success of the Coastcare programme on Coconut Island, a comprehensive community level education and extension programme. Better use of existing land through "town" planning processes is also encouraged. For example, a large part of all occupied Torres Strait islands is taken up by runways used at best for a handful of flights each day. Whilst good communication is essential, better placement of these facilities, and ultimately a more restricted but carefully considered network of landing strips within the Strait may be necessary to free up valuable land.

More radical options have also been considered. On Coconut Island the authors have been involved in assessment of schemes to enlarge the island (and change its shape to a more stable oval form) by adding between 8 and 15 hectares to the southern shore. The material would come from dredging to a depth of 1.5m in the central reef flat. Minimal environmental impact on the heavily sedimented reef flat is envisaged from such a scheme. Indeed, it could produce an attractive and productive shallow lagoon, though the effects on sediment supply and maintenance to the island would need assessing.

Hard engineering solutions are generally not recommended on unconsolidated reef islands and where attempted have often been disastrous (e.g. SOPAC, 1994). However, soft engineering such as beach replenishment is worthy of consideration. The major problem on reef islands is a source of easily and locally accessible materials, especially sand. On Coconut Island, the problematic harbour location is a *fait accompli* and hard engineering would be both expensive and have the potential to focus erosion elsewhere. The most effective short term measure for the most affected north-western shoreline is the armouring of the beach by coral rubble and boulders in the form of a deformable rubble mound structure as has been used elsewhere (Byrne, 1994). The advantages are that such materials are already available both on the reef flat and off-reef, and the 'beach' is already one of beachrock and rubble and would therefore suffer no more aesthetic deterioration. Over time the local wave climate would modify the original morphology into a naturally stable form.

Increased awareness of, and expenditure on the islands of Torres Strait has occurred in recent years in response to security, economic and environmental needs (see for example references in Zann, 1995). Issues raised include the maintenance of sustainable fisheries, increasing use of major shipping lanes through the Strait (up to 2000 large vessel movements per year), run-off from the Fly River in Papua New Guinea and pollution problems associated with large mining projects within its catchment, and the proposed development of the Chevron gas pipeline across Torres Strait from Papua New Guinea.

In addition concerns have been raised about the effects of global climate change and sea level rise on the Torres Strait Islands. Even without this increased pressure (which in any case may not be as serious as some suggest, see Hopley, 1993 1997b) we contend that the erosion problems of the coral cays of Torres Strait need immediate management consideration if the viability of the islands as a place to live is to be maintained.

ACKNOWLEDGMENT

This paper is based on a number of consultancies carried out on Torres Strait islands over the last 4 years. We acknowledge the contributions of colleagues Michel Pichon and Michael Huber to these projects, the help provided by Edmiston and Taylor, Cairns, the consulting engineers for whom the work was undertaken, and the island councils and communities who helped in numerous ways.

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LOW COST SOLUTION APPLIED TO STABILISE A BEACH-ESTUARY AREA. CASE STUDY

Jurek Piorewicz

Central Queensland University
Rockhampton, Queensland, AUSTRALIA
j.piorewicz@cqu.edu.au

ABSTRACT

When discharge from an estuary is partly blocked by the construction of a causeway, the natural regime is changed, and initially unpredictable changes to the relationship between the nearest beach and the new output can occur. A case study has been made of an estuary that was partly blocked by a causeway 58 years ago. Progressive erosion of the beach named Kinka Beach (Capricorn Coast, Australia), and instability of the outflow channel from the man-made Causeway Lake were halted by the excavation of a new channel and the construction of a sand dam. The new dam created a tidal lagoon which accumulated a tidal prism sufficient to keep the new channel free of siltation. At the same time the dam may be considered as a natural headland for nearby Kinka Beach where a crenulate shaped bay was expected to develop.

The fundamentals of the implemented solution, and the status of the beach after 8 years, are presented. The effect of this relatively cheap solution on the nearest beach is very positive. In the author's opinion the presented solution could be recommended as an environmentally friendly "soft" solution for beach stabilisation with low management requirements.

INTRODUCTION

The basis of much scientific and engineering education is mathematical equations: if the correct numbers are substituted in the appropriate equation, the correct solution will be obtained. Most scientists and engineers recognise that it is often difficult to obtain accurate input data and that many of the equations are simply the best approximation currently available. It is no wonder that many problems can be hypothesised and not dealt with rigorously by mathematics. This is where engineering begins and science ends since solutions must be found with a degree of intuition (Silvester and Hsu, 1997).

The problem discussed in this paper belongs to such a case where an engineering construction in the active coastal zone implemented some 50 years ago, required some human intervention to preserve life and maintain the coast for future generations. The solution to this problem must fulfil local community expectations and be economically affordable.

The Capricorn Coast (Figure 1) is the name of the Central Queensland coastline from Cattle Point on the northern side of the Fitzroy River mouth northward to Stockyard Point, a distance of about 90 km. Yeppoon is the major town on the coast, the other is Emu Park, located about 18 km south of Yeppoon. The favourable climate and recreational opportunities have encouraged extensive residential and commercial development.

In the last 15 years the population has increased from 11,500 to about 21,000 people at present (1998) living along the Capricorn Coast. It is evident that the attractiveness of the Capricorn Coast is growing. In such a situation, the problem of the beach conditions, its stability and vulnerability to erosion is very real. Any erosion caused by storms results in public demand for implementation of more and more effective measures to protect the coast and public assets against possible erosion.

Kinka Beach, located on the Capricorn Coast, is an example where progressive beach erosion threatens the safety of the road and local people. The history of local community activities to force the local government to initiate investigation and implement some solution, could be a good example of development of a Coastal Zone Management low cost strategy for places of (relatively) secondary value.

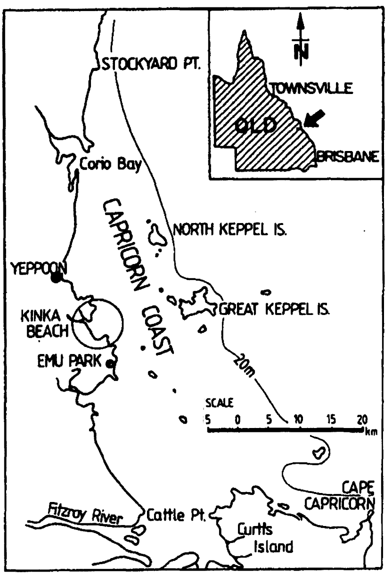


Figure 1. Capricorn Coast - locality plan

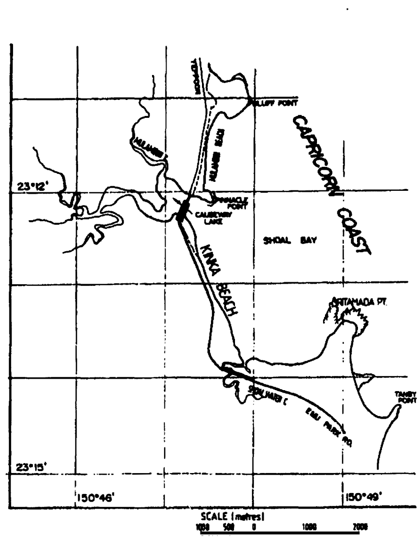


Figure 2. Kinka Beach region

CASE STUDY: KINKA BEACH

History of Kinka Beach Progressive Erosion

The sandy Kinka Beach (Figure 2) is in the region of high semidiurnal tide with a range up to 5.1 m and a wide, flat intertidal area up to 800 m in width. Originally Mulambin Creek represented a wide (about 500 m) estuary with an estimated 1.6 mil m^3 tidal prism.

Serious changes have taken place along Kinka Beach, particularly in its northern and central parts since a causeway and bridge across the mouth of Mulambin Creek were constructed in 1939 for the scenic view road which linked Yeppoon and Emu Park. This construction formed a permanent lake called Causeway Lake into which the tide flow was possible only when tides were higher than bridge sill level. The invert of the floor of the waterway under the bridge is such that only tides exceeding 3.7 m will flow through the 60 m wide bridge.

Following construction of the causeway and bridge, the original river mouth cross-section became quite unstable. A large accretion of sand had since occurred on the seaward side of the causeway, and Mulambin Creek had been forced to flow south from the bridge parallel to Kinka Beach. In the years since the causeway was built, approximately 1.1 million m^3 of sand have accreted in the sand spit in front of the original mouth of Mulambin Creek. This equates to an average of approximately 23,000 m^3/y of sedimentation since initial construction. Uncontrolled flow from the creek, in conjunction with wave action, has caused extensive erosion in the central beach area, and reduced the dune width by about 60 m in the period 1960 - 1985. Figure 3 presents aerial photographs from different years to show progressive changes along the coast.

To protect the road and local properties, rocks have been dumped along the seaside of the dunes since 1982. Initially of a length of 250 m, up to 1988 this temporary rock wall had been extended to a total length of about 750 m. Considering its temporary standard, the wall is not expected to withstand a severe storm event. Remarkably, it will be noticed that on both ends of this rockwall there was extensive local erosion. On the northern end erosion was of the order of 10 m reaching almost to the edge of the road. It confirms the finding of McDougal, Sturtevant and Komar (1987) with regard to the depth of erosion on the ends of a seawall.

Applied Solution

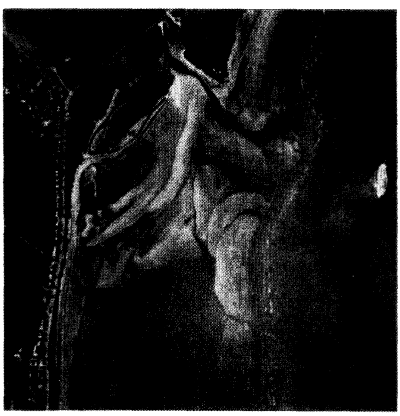
Central Queensland University (CQU) undertook investigations in 1987/88 to remove the risk of further erosion in the area. Considering that heavy beach protection has always been very costly, the establishment of a stabilised dune system and its proper management is a far cheaper and sometimes better solution. These are generally called "soft" solutions (or "environmentally friendly solutions") for beach protection. The recommended solution for Kinka Beach belongs to this category. It is based on two hypotheses: each of them is based on observation of nature and some experiments, but each is still without a full explanation by theoretical fundamental studies. This "soft" solution involves a new dredged channel and tidal lagoon (Figure 4).

The principles of the solution are based on Per Bruun's (1978) findings about the dynamic stability of an inlet channel and Silvester's (1972) concept of a crenulate shaped bay. On the basis of these two hypotheses a "soft" solution was proposed. The solution involved the initial dredging of a new channel. Simultaneously, the natural dune system was extended in the form of a sand dam (a total length of 750 m). The objective proposed being to create a tidal lagoon with a capacity sufficient to increase the Bruun's index (relationship between the spring tidal prism, P, and the annual gross longshore transport volume, M, passing the entrance) to some arbitrary level around 100 (the investment cost factor influenced this level). The area of the lagoon which was created was about 15 ha. Further improvement in the stability of this region was expected by way of natural processes within a reasonable time period.

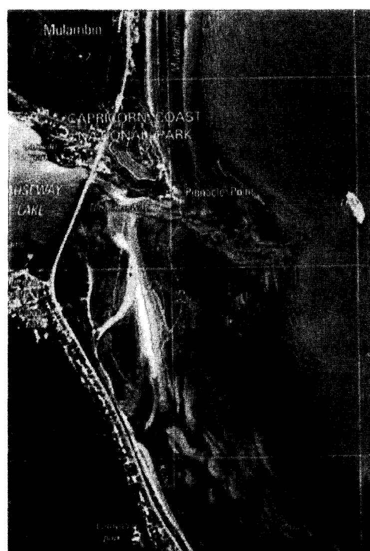
The initial construction, including the opening of the new channel, was performed in May 1988 with the final shape of the sand dam being established in November 1989. To protect the sand dam against wind erosion in its initial stage, the local council (Livingstone Shire Council) built a windscreen 1 metre high along the whole dam and planted *spinifex hirsutus*.

(a) 1961

(b) 1975



(c) 1989



(d) 1995

Figure 3. Changes to the region Kinka Beach/Causeway Lake for the period 1961 - 1995. Arial photographs (a) 1961 year, (b) 1975 year, (c) 1989 year, just after sand dam construction, (d) 1995.

The total cost of the project implementation was below A$100,000. Any other traditional engineering solution would have been much more costly and would not have considered the stabilisation of the shoreline on the basis of the daily processes. A properly designed rockwall would cost about A$3,000 per running metre. The nourishment, with a cost of about A$5 - 7 per m^3 of supplied sand would also be very costly in this case. Additionally, the never ending repetition of supplying sand could be discouraging, and would require some additional measures.

Analysis

Waves affected the Capricorn Coast may be generated locally within 150 – 300 km or may arrive as decaying swell. One percent exceedance of significant wave height is about 2.5 m whereas 99% exceedance is 0.25 m. For the locally generated waves the average wave period is $T = 4.9\sqrt{H_{sig}}$. The dominant direction of the swell is from east to southeast. Typical swell wave steepness is 0.006 and period $T = 10\sqrt{H_{sig}}$. The nearshore wave conditions are determined by refraction of the offshore waves.

Initial calculations with Bijker's method shown the longshore transport to be approximately 14,000 m^3/y. The calculations were verified later using Van Rijn's (1989) approach which include tidal currents. General flood tide direction in the intertidal zone is northward of the order of 5 to 15 cm/s and ebb tide is southward. Tidal currents are not regularly distributed and they strongly depend on the bathymetry of the nearest area. Therefore, it is practically impossible to represent the tidal currents with high accuracy and some simplifications are justified. Introducing tidal currents into sediment transport calculations caused a much higher mobility of the bottom material. The net result of the transport is, however, very close to the calculation without tide currents, as it can be seen in Table 1. The calculation were carried out

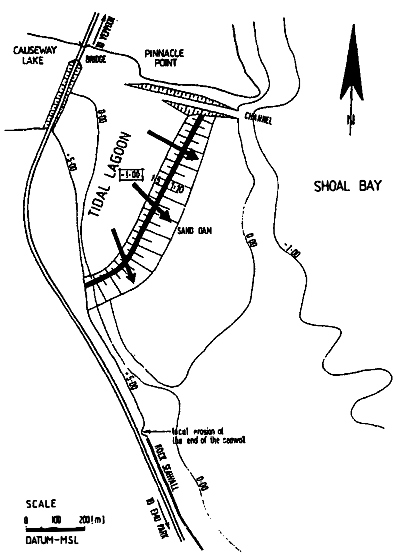


Figure 4. Applied solution: tidal lagoon and excavated channel

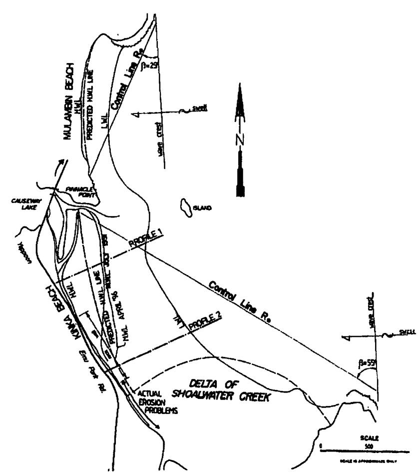


Figure 5. Predicted shape of the Kinka beach and the actual movement of the beach line

for two selected profiles (1 and 2 marked in Figure 5), and for the average annual wave conditions with the neap tide of the range of 1.6 m and the spring tide of the range of 3.4 m. The average sedimentation between profiles 1 and 2 was finally in the order of 6700 m^3/y, considering tide currents, and 8000 m^3/y, when tide currents were omitted from the calculation.

The new channel shows a tendency to widen and become shallower at the seaward end. Such a situation is described by Per Bruun (1978) when his index, P/M, is between 50 and 100. By constructing the sand dam, part of the northward longshore sediment transport was trapped and settled in the shadow of the dam. This sediment transport compared with the total tidal prism encompassed by the lagoon and Causeway Lake brings the index to a level of 50 with a decreasing tendency at present. Its arbitrary value strongly depends on the width of the nearshore zone considered during calculation.

Table 1. Results of the longshore sediment transport calculation for Kinka Beach using Van Rijn's model

Profile	Tidal currents	Distance	Cumulative transport [m^3/year]			Sedimentation
			to Nth	to Sth	Net	[m^3/year]
			Neap tide			
1	yes	1300	35600	-8500	27100	
2	yes	1300	38200	-5200	33000	5800
1	no	1300	24500	-9700	14800	
2	no	1300	27000	-4600	22400	7600
			Spring tide			
1	yes	1300	34200	-7400	26700	
2	yes	1300	39000	-4700	34300	7500
1	no	1300	21600	-8800	12800	
2	no	1300	25800	-4500	21300	8500

If the lagoon embankment is considered to be a headland, the dynamically stable shape of the beach will grow and the dune will become reconstructed by nature's action. The oblique angle created by the dominant swell crest line and the control line, connected two fixed points called headlands, dictates the stable shape of the beach. This concept, developed by Silvester, allows prediction of a stable shape of the coastline if no sediment is supplied i.e., no gradient exists in a longshore sediment transport. Table 1 shows that the sediment transport is relatively low. In such a case the concept of crenulate shaped bay was adopted for the Kinka Beach. Figure 5 shows predicted and observed changes in the beach line. This trend is visible also in Figure 3. The analysis was carried out on the assumption that swell waves, after refraction, approach Kinka Beach from the same direction as for the neighbouring Mulambin Beach. This allowed verification of an angle of approach required for drawing the beach contour line in relation to the control line.

Accumulation and smoothing of the bottom contour are visible in this region. It is also important to notice that one-third of the rock wall from the north has been covered completely by the sand dune (Figure 6). Well established grass on this dune indicates its strength and stabilisation. The covering of the rough rocky sea wall by the sand dunes could be considered as a positive effect of the adopted solution towards restoring the natural beauty of the beach.

The volume of sedimentation along Kinka Beach has been analysed based on irregular surveying. A total 87 ha of the adjacent coast between profiles 1 and 2 (Figure 5) has been covered by surveying. A total 284,000 m^3 of sand has been accumulated up to 1995. The process of sedimentation began practically from November 1989, thus the average annual sedimentation in this region is about 40,000 m^3/year. The average depth of sedimentation for the period 1988 - 1995 is 45 mm/y

The other survey undertaken in April 1998 indicates the average depth of sedimentation for the period 1995 - 1998 as 27 mm/y. Figure 6 shows the total average depth of sedimentation along the monitored section of Kinka Beach since the sand dam was constructed. Thus the actual process of sedimentation may be considered as a positive effect of the implemented construction leading towards restoration of the natural strength of this beach.

The sedimentation calculated, based on the longshore transport analysis only, may give a large error when compared with the real measured sedimentation. This indicates that in the case of macro tidal beaches, cross-shore transport could play an important role and should not be omitted from analysis. The surveying of the profiles 1 and 2 shows that the main reason for such high sedimentation is slow movement of the nearshore sand bar towards the beach. Wreckage of a car located about 500 m from the dunes, between profile 1 and 2, was visible some years ago but now is completely covered by the sand bar.

Kinka Beach Situation May 1989

Kinka Beach Situation May 1997

Figure 6. Improvement of the Kinka Beach dune system since the project implementation.

Coastal engineering structures are generally more related to storm protection than to stabilisation of the shoreline on the basis of the daily processes, which are so important in shaping the beach. The effects of this project indicate that the existence of a stable crenulate shaped bay could be a very promising means of stabilising a shoreline. In spite of a lack of adequate theory of such bays, this method of beach stability has become more and more accepted and artificial headlands have been built around the world.

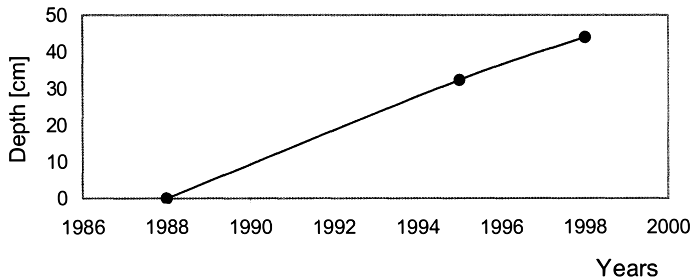


Figure 7. Cumulative depth of sedimentation on 87 ha of the adjacent coast of Kinka Beach observed for the period of 1988 - 1998 (after sand dam was constructed).

Some learning outcomes from the project realisation and maintenance

1. The head of the sand dam was not constructed as a fixed point using, for example, geo-textile sand bags.

   During the past 10 years up to 150 m of the sand dam is missing and the sand has been pushed into the tidal lagoon causing a reduction of its capacity and a reduction of the tidal prism volume required to keep the channel open. The washing of the head of the sand dam means also that this point cannot be considered as a fixed point for developing a stable crenulate shaped bay.

2. The new sand bar created by nature in front of Kinka Beach creates an additional unwanted tidal lagoon

   Reshaping of the coastline started in the form of a sand bar where wave energy is strongly dissipated. With the tide rising, water overtopped the bar and filled up the space between the sand bar and the beach. A slow sedimentation process occurs in this area. However, during the ebb tide when water moves back to the sea, the sand bar becomes a barrier for the water flow. Flow starts along the beach to the end of the sand bar, then towards the sea. Thus an unwanted second tidal lagoon was created with its own tidal prism and stability process. This situation became very serious on Kinka Beach six years ago. It required human intervention and local dune protection by dumping a few tons of rocks.

   Such a situation could have been avoided if additional pumping of sand from the tidal lagoon on the beach had been undertaken at that time to accelerate the natural process which had been initiated.

Both situations occurred because of financial limitations during realisation of the project. The later approach of the local Shire Council to the maintenance of the area was also financially limited. Therefore, it could be considered that the approach of "do nothing" until the time when capital work must again be undertaken may be justified for the following reasons:

1. For the last 10 years natural coastal processes were allowed to continue, causing an increase of dune volume and covering of the rockwall on 75% of its length.
2. The cost of maintenance would be much higher than the cost of repeating earth works, if required, after 10-year period.
3. The existing beach amenity is preserved without additional man-made structures on the beach.
4. Irregular monitoring of the coastal changes is carried out by CQU in co-operation with the local Shire Council.

CONCLUSION

It is well accepted that no ideal solution exists for erosion control. The wave climate, tidal range, and longshore transport, are among the many variables that must be considered at each individual site. Traditional engineering approaches to the stabilisation of beaches near river mouths or estuaries include the use of jetties or groynes, rockwalls and nourishment. Nourishment, now widely used, has the advantage of leaving the beach uncluttered with structures, and of not risking damage to adjacent shores. Its main disadvantage is the need to periodically replace the losses seaward and/or alongshore.

Engineering structures are generally more applicable to storm protection than to shoreline stabilisation with respect to daily processes which are so important in shaping the beach. The concept of the existence of stable crenulate shaped bays could be a very promising means of stabilising a shoreline in the areas of low longshore sediment transport but requires more theoretical studies.

In the case of Kinka Beach, construction of the sand dam has created a tidal lagoon to accumulate sufficient tidal prism. At the same time the dam was considered as a natural headland for the nearby beach. The future shape of the beach was predicted on the basis of empirical relationships between swell direction and physical parameters of the bay. The obtained results are very promising.

To its advantage the implemented solution, with an initial low cost, has been further improved by natural forces and is environmentally acceptable. Sand accumulation of about 40,000 m^3/y over a distance of 1 kilometre southward from the constructed sand dam, and the creation of a natural sand dune which covers the existing rockwall, are obvious and positive effects of these natural forces.

It is well known in coastal engineering, that beach stability projects are usually implemented without prior knowledge of the degree of likely success. Monitoring of the chosen solution and structures which are in place, therefore, is very important in order to learn more about natural forces. That information, together with continuous development in theoretical studies, will allow for more rational criteria for the design and construction of features to stabilise coastlines.

From the maintenance point of view it is important to consider economical aspects of the solution and therefore the coastal zone manager may consider that an option "do nothing" after project implementation may be neither a risk nor an expensive solution, in some cases.

ACKNOWLEDGMENT

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ASSESSMENT OF CALIFORNIA'S OCEAN WAVE ENERGY RECOVERY

Young C. Kim

California State University, Los Angeles
Los Angeles, California, U.S.A.
ykim@calstatela.edu

ABSTRACT

With the prospect of an increasing shortage of energy resources, there has been a growing interest in renewable alternative sources of energy. This paper summarizes the availability of California's coastal and ocean wave energy resources and examines the potentials and limitations of existing conversion technology for energy development in California.

In the last two decades, considerable research and developments have taken place in ocean wave energy conversion technology. Suitable conversion technology for California include: (1) Wave power extracting caisson breakwater, (2) Backward Bent Duct Barge, and (3) Wave energy extraction combined with desalination. Recommendations based on the engineering, environmental, and economic evaluations were made for future California's coastal and ocean wave energy conversion technology.

DEVELOPMENT OF OCEAN WAVE ENERGY CONVERSION TECHNOLOGY - GLOBAL OVERVIEW

Classification of Ocean Wave Energy Conversion

There are more than a thousand different proposals for the utilization of wave energy in the patent literature (McCormick, 1981), and there are many ways to describe and classifying them. Figure 1 shows the classification of ocean wave energy conversion systems adopted by G. Hagerman. These devices can be classified into the following five categories:

1. Heaving
2. Heaving and Pitching
3. Pitching
4. Oscillating Water Column
5. Surging

Development of Ocean Wave Energy Conversion Technology

For heaving float devices, the KN System by Danish Wave Power was conducted with 45 kW prototype in the North Sea. The Gotaverken's Hose Pump Wave Energy Conversion which has been conducted since 1980, is based on the "hose pump", a hose with helical pattern of steel wire reinforcement, which causes the hose to constrict when stretched. DELBUOY, two point absorber systems for wave energy extraction, has been developed by the International Science & Technology Institute, Inc. in the U.S. This system comprises a light weight, shallow draft cylindrical buoy driving a submerged, single-acting positive displacement pump tethered to the seafloor. The motions of the buoy open the pump for the pressure stroke with energy stored in the natural rubber return springs used to refill the system. The water power desalination can be achieved by the reverse osmosis. Full scale system tests were performed at the University of Puerto Rico in 1980-85, and 350 gpd pilot commercial unit has been in operation at Coffin Island in Puerto Rico.

A Parallel Disk Wave Energy Module developed by the U.S. Wave Energy, Inc. combines the heaving and pitching motion. It consists of two parallel discs connected with hydraulic piston pumps. One disc is buoyant and rides on the ocean surface while the other is suspended at a depth where motion due to waves is small. Hydraulic fluid is transferred from the piston pumps to a high-pressure accumulator and is then fed to a hydraulic motor connected to a generator. 1 kW, 1:10 scale model tests were performed on Lake Champlain, Vermont. The Contouring-Raft Wave Energy Conversion System by Sea Energy Corporation uses the heaving and pitching motion. Test of a prototype 500 kW "one-raft" system has been conducted for regular and random waves.

For pitching devices, Salter from the University of Edinburgh has developed a very efficient wave energy conversion device known as Salter Duck. The Duck is a cam shaped device that oscillates about a spine connecting many devices. The spine is long enough to span several waves and provides a steady frame of reference for power extraction. 1:10 scale model tests were performed at Lock Ness. The Tandem Flap Wave Energy Converter by Q Corporation uses two flaps which are hinged at the bottom and allowed to move in the direction of wave. Because of its ability to capture both incident and a portion of the transmitted wave energy, it is significantly more efficient than a single flap device. A 10 kW Tandem Flap Wave Energy Converter system was tested in Lake Michigan in 1987. A Pendulor system was developed by Professor H. Kondo at the Muroran Institute of Technology in Japan. The pendulor is a pendulum gate which swings backwards and forwards in the opening at the front of a chamber facing the incident waves. The back of the chamber is a fixed wall, located a quarter wavelength behind the axis of the pendulum pivot. A 5kW system has been in operation in the bay of Uchiura near to Muroran in Hokkaido, Japan.

Oscillating Water Column incorporates a wave-excited oscillating water column and a pneumatic turbine. The air above the water column is alternately compressed and expanded resulting in an alternating pressure difference across the turbine. A one-meter Pneumatic Wave Energy Conversion System was tested in the second deployment of the KAIMEI in the Sea of Japan in 1985 (JAMSTEC, 1987). A 500 kW prototype, Multi-resonant Oscillating Water Column by Kvaener, Norway, was constructed in 1980. In Japan, Shore-Fixed 40 kW Wave Power Plant was constructed on the shore of Sanze, Sea of Japan. This plant consists of a caisson and air turbine generator, and Tandem Wells turbine was selected. The Wave Power Extracting Caisson Breakwaters developed by Y. Goda of Japan while he was with the Port and Harbor Research Institute has been built at Sakado, Japan. Caissons function as a breakwater and a wave power device at the same time. Another concept, Backward Bent Duct Buoy, developed by Ryokuseisha Corporation has an air chamber bent backward from the wave direction. Its originator, Y. Masuda, reported that this configuration of floating platform has a superior performance and that it has excellent conversion efficiency with low mooring force. A 2.4 m scale model was tested at Yura in 1987 and at Mikawa Bay in 1988. Recently, Professor M. McCormick at Johns Hopkins University conducting tests for optimum design of the Backward Bent Duct Buoy system.

For surging device, Tapered Channel known as TAPCHAN has been in operation since 1986 at Toftestallen, Norway. This Norwegian device converts the wave energy into potential energy in a reservoir on the shore.

ASSESSMENT OF CALIFORNIA'S OCEAN WAVE ENERGY RECOVERY

Resource Characteristics

Monthly average wave power can be computed as J = 5.7 H where J is the monthly average wave power in kW/m of coastline and H is the significant wave height which is the average height of the highest 1/3 waves. Thus the wave energy is directly proportional to the square of the significant wave height. For example, at Santa Cruz, California, the average significant wave height is about 2.4m which can be expressed as J of 26 kW/m of coastline.

As waves generated in deep water travel shoreward across the continental shelf, they lose energy due to bottom friction and refraction. Furthermore, the incident wave power at the coast is much lower than offshore. A study by Hagerman shows that the energy at deep water north of Point Reyes, California is about 30-35 kW/m. This will be reduced about 25-30 kW/m as waves approach the Continental Shelf and reduced to about 5-15 kW/m at the water depth of 10-20 m at the coast. At the South of Point Reyes, California, the energy level is 25-30 kW/m and it reduces to 20-25 kW/m at the Continental Shelf. The annual average significant wave height at the Central California is to be about 2.0m while at the Southern California it drops to 80-90%. That means the power of 15-20 kW/m at the Central California will be lowered to about 10 kW/m at the Southern California. Therefore, it can be concluded that there is a reduction of about 5 kW/m of energy as wave travel from deep water to continental shelf another drop of 10 kW/m at the coast. A drop of 5 kW/m of energy is expected as we move from the Central California to the Southern California.

Not only there are geographical variations, but also seasonal as well as year-to-year variations. It is well known fact that the incident wave power on the west coast during the winter month is the highest and the summer months is the lowest. Data also show that between 1981 and 1985, there is a variation of annual wave power. The frequency of low-wave events, that is when the significant wave height is less than 1m, increases as we move from the Northern California to the Southern California. Conversely, the frequency of high-wave events increases as we move from the Southern California to the Northern California.

Economics of Wave Power

Land-based Tapered Channel technology, developed in Norway, is on the verge of commercialization and Japanese caisson-based systems are expected to enter the Pacific island market during the next five years. G. Hagerman's earlier study on the cost and performance of caisson-based wave power plants shows the following:

<u>Device</u>	Double-Acting MOWC	Double-Acting MOWC	Single-Acting OWC	Pivoting Flap
<u>Developer</u>	Kvaemer Brug	Kvaemer Brug	Takenaka	Muroran

	A/S	A/S	Corporation	Institute of Technology
Location	Toftestallen (Norway)	Tongatapu (Tonga)	Kashima Port (Japan)	Muroran Port (Japan)
Cost of Energy	16-17 c/kWh	19-21 c/kWh	33 c/kWh	20 c/kWh

This data indicate that the energy cost for the caisson-based wave power plants is around 20 c/kWh.

There has been much less full-scale experience with offshore based wave energy devices than with caisson-based systems. Data from Bellamy, Hagerman, and Rasmussen for the cost and performance of offshore wave power plants show that:

Device	Circular SEA Clam	Swedish Heaving Buoy	Swedish Heaving Buoy	Danish Heaving Buoy
Location	Lewis (Scotland)	Half Moon Bay (California)	Makapuu Point (Oahu, Hawaii)	Hanstholm (Denmark)
Cost of Energy	15 c/kWh	13 c/kWh	8.6 c/kWh	22-26 c/kWh

Comparing the energy cost for caisson-based and offshore based wave energy, the energy cost for offshore based is certainly cheaper than that of the land or caisson-based.

Various co-products can be obtained with wave energy production. These are:

1. Seawater renewal for closed-pond aquaculture
2. Fresh water for household use, crop irrigation
3. Breakwater protection for ports and harbors

A heaving buoy device (DELBUOY) was developed by Hicks for the desalination of seawater by reverse osmosis. Since 1982, a full-scale prototypes has been deployed off the southwest coast of Puerto Rico, producing fresh water at a rate of 950 liters per day from a single buoy. Combing wave energy generation with breakwater protection at coastal harbors will be attractive alternative.

Data from Hagerman, Vega, Hemphill, and Doyle for energy cost comparison with other options show that when Wave, OTEC and Coal options were considered, the Wave option is cheaper than OTEC while Coal is the cheapest among three. When Wave, Wind, and Coal options were compared, the Wave option is the most expensive among the three.

California's Development Opportunities

The annual average wave power of California coastline is said to be about 4,900 MW. Assuming that about half of this power can be extracted, it is still large power resource along the California coast. The most attractive revenue-generating projects would be the one with wave power plant for electricity with co-products. Examples of such projects are ones with electricity with breakwater protection and electricity with fresh water as by-product.

Construction of caisson-type breakwater with oscillating water column device will be the ideal solution for coastal communities, specifically home port to a large commercial fishing fleet. Ideal candidates for this project will be Noyo Harbor in Fort Bragg and projected harbor construction at Santa Monica.

High-pressure seawater could be tapped to fresh water by reverse osmosis and electricity by passing the reject brine through a Pelton turbine. DELBUOY, heaving buoy systems for offshore use, has been proven to be a success in getting fresh water in island communities. Ideal candidates for this project are Santa Cruz, Santa Rosa, San Miguel, Santa Catalina, and San Clemente Islands.

CONCLUSION\

1. Annual average wave power of California coastline is said to be 4,900 MW. Wave power in the Northern California is around 15-20 kW/m while the wave power in the Southern California is 10 kW/m.

2. For plant sizes of 30 MW or less, the cost of wave-generated electricity is lower than for other ocean energy technologies. The wave power is also less expensive than small hydropower or diesel generation.

3. Co-products enhance wave power's economic appeal. To construct breakwater in the coastal communities, a caisson-type breakwater with oscillating water column is recommended. To obtain fresh water in the island communities, heaving buoy system is recommended.

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DEVELOPMENT OF A NEW WAVE ENERGY GENERATING SYSTEM

Kyu-Bock Cho[1] and Hyun-Jin Shim[2]

[1]Department of Electrical Engineering, Hanseo University
KOREA
Chokb@soback.kornet21.net

[2]Baek Jae Engineering
Seoul, KOREA

ABSTRACT

In this paper a new wave energy generation device is presented, which could provide a clean and inexhaustible supply of energy. The components of the wave energy generating system are the sea surface structure (buoy, triangular yoke and drum), rotary shaft and rotating arm, lower structure (lattice form floating frame and supporting structure) and anchoring system (anchor block and rope). Compared with other systems, it has shown many novel features, including a floating, lattice structure fabricated from plastics and composites, incorporating an array of small wind turbines. The device has been assessed in more detail and so this paper describes only the main conclusions of the earlier assessment. It is likely to be economically competitive with a range of electricity generation technologies if deployed in energetic wave climates such as those of Western Europe

INTRODUCTION

Background of development

Two energy shocks in 70's triggered developed countries to develop substitute energy competitively, while there have been some positive results such as wind power, and geothermal, yet it is true that utilization of wave power is still far away since it is insufficiently competitive with conventional energy.

Although the existing energy systems such as fossil and atomic energy have contributed to industrial development and the wealthy lifestyle of mankind, many scientists warn of the shortage of fossil energy sources within the near future. There is also concern over environmental problems such as global warming and abnormal weather change, air pollution and radioactivity. An environment-friendly energy system should be renewable, perfectly clean, and must provide almost unlimited amount of stored energy source, which is easy to exploit, on the earth. It should be also simple to maintain and to manage and also economical. The search for renewable energy has concentrated on a range of technologies to harness energy from a variety of natural sources such as the sun, the wind and the waves. Whereas some technologies have progressed to a commercial stage any further viable developments in renewable energy should be welcomed. One particular approach might be to design a device, which harnesses energy from more than one of these renewable sources.

Recently it was also announced that the industrialized countries would sign the Kyoto Protocol, which signifies the intention of countries to ratify the agreement reached at the UN conference on climate change. The targets set at Kyoto have yet to receive ratification in the industrialized countries. They believe that the promotion of emission saving technologies is one way to signal to the more reluctant parties that the UN is serious about its stance on the environment. They want Member Countries to be encouraged to meet their own targets for reductions in greenhouse gas emissions by setting national targets for energy from renewable sources such as wind and wave.

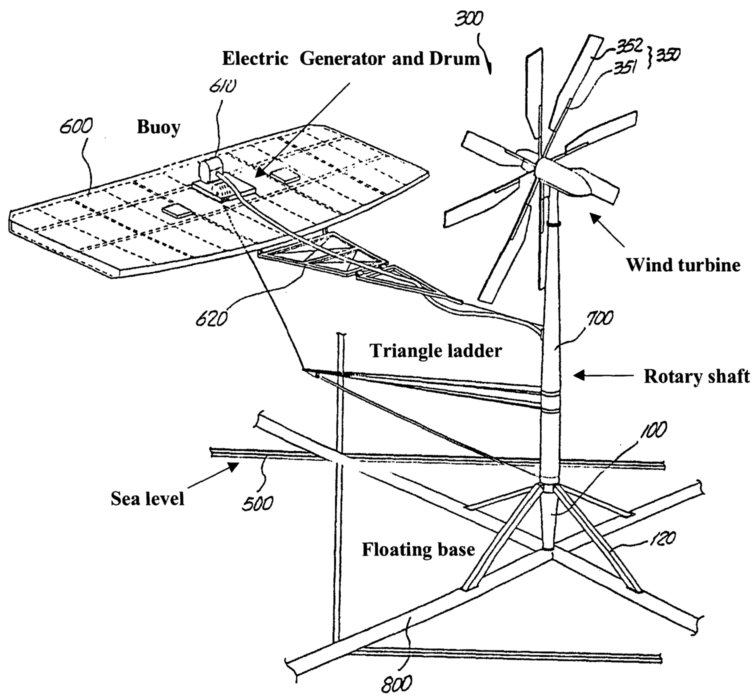

Fig. 1 Outline Design of Wave-Wind Power Generation Device

A possible fundamental solution to these problems is the development of clean and renewable energy sources, which are inexhaustible and economically competitive. These clean and renewable energy sources, such as a new combined hybrid system with solar energy, wind and/or wave system, can then replace some conventional energy resources. The estimated amount of electricity generation would be about 30,000-60,000kW/100km^2 according to local wave power density. It is estimated to be about 70% or more than how much energy the human being needs.

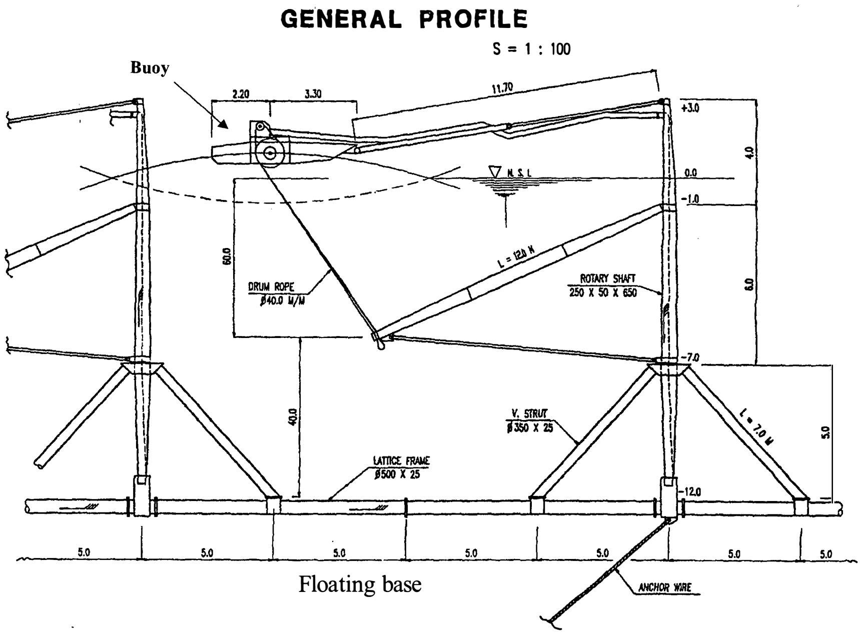

Fig.2 Overview and Basic Structure of Wave Generating Device with a Buoy

In the last few years a policy of decentralizing electricity generation resources has appeared throughout the world. The deregulation context and attractive cost have particularly encouraged this. The Danish government's plan Energy 21 (Danish Ministry Environment Energy, 1996) aims at reducing CO_2 emissions by 50 percent by the year 2030.

In relation to this, the potential for offshore wind turbines has been examined. The calculations set out in Energy 21 include 4000 MW of large offshore wind farms in Denmark in the year 2030 in addition to the expected 1500 MW of onshore wind power distributed on smaller, more geographically scattered wind farms. The Minister for Environment and Energy is expected to issue a decree that the electricity utilities should start investigations and construction of large offshore wind farms totaling 750 MW by the year 2007.

Recently also during CIGRE sessions, in connection with the construction of large offshore wind farms in Denmark, a system analysis result on integration of wind power into the power system has discussed. The analysis included two test sites and the full expansion. The location of offshore farms requires long submarine cables. For the test sites it is most likely possible to use a. c. cables for 150 kV. Choice of generator type is a key question for the system requirements that the utility can set. However the large amounts of non-dispatchable wind power give rise to a flow of inadvertent power out of a specific network system (Jensen and Sorensen, 1998), (Christensen et al., 1998), (Adam et. al., 1998).

In this regards, comparing with other systems the proposed new hybrid wave energy generating scheme in this paper incorporates many novel features to reduce overall capital costs, utilize cheaper construction materials and minimize non-productive wave loading on the device. (Fig.1)

THE WIND-WAVE ENERGY GENERATING SCHEME

Basic components

This scheme consists of a floating base, rotary shafts, a buoy, and wind turbine as shown in Figures 1-5. The floating base in Fig. 2 is made up of pipes which form a lattice containing pressurized air and is later moored evenly in the local water. The shafts in Fig. 3 can rotate

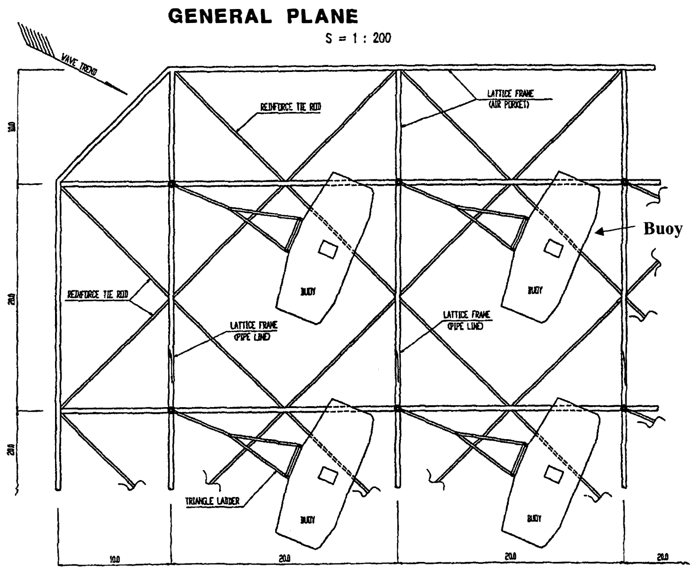

Fig.3 Arrangement of Buoy Detailed Structure of a Buoy

360° around the floating base and the rotary arm is connected to the end of drum-rope in a buoy. (See also Figs. 1-2) The buoy in Fig. 4 with its surface completely sealed tight contains a drum, a clutch, a pump (or a compressor), and a generator is installed. This is moored to the rotary shaft by using a triangle ladder. The generation of electricity occurs by converting the movement as the buoy oscillates up and down in the waves. The wind turbine is installed on an extension to a rotary shaft and energy is attained from wind power. Fig. 5 depicts the outline of electrical system design of wave-wind power generation device.

Basic scheme

The buoy in Fig. 2 is moored via the triangular yoke, to the rotary shaft and oscillates up and down as a result of wave action. The vertical movement of the buoy induced by the passage of waves causes a rope to wind on and off a drum housed within the buoy, thus transferring the vertical force into a rotary force. The resultant rotary force is transmitted to the power generating system housed within the buoy. The size of the buoy can be chosen to extract energy from the most frequently occurring wave height. This rotating shaft enables the buoy to orient itself at right angles to the oncoming waves, to ensure maximum capture efficiency.

The basic wave energy system can be converted into a wind-wave energy system by installing small wind turbines of 8m diameter using an extension of the rotary shaft. Each blade of the wind turbine is pinned at its connection to the hub, thereby allowing it to rock back and forth under the action of a restoring spring. This arrangement provides a means of limiting the horizontal forces experienced by the turbine blades during periods of high wind.

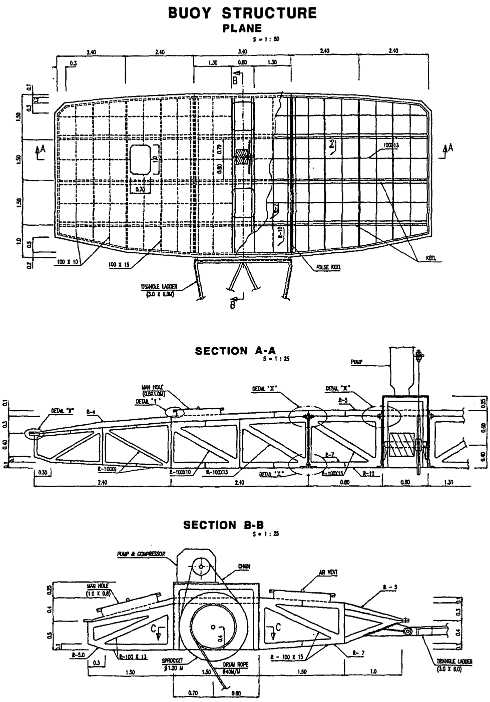

Fig.4 Detailed Structure of a Buoy

This reduces the cost of the supporting shaft. The blades are mounted downwind of the supporting shaft in their own nacelles, thereby allowing the turbine to orientated itself with respect to the wind direction.

The lower structure serves to tie the buoys together, holding them at the required separation distance and providing a reaction frame against which the buoys can operate. The structure also supports the wind generating turbines. This structure consists of a lattice form consisting of hollow pipes containing compressed air to provide buoyancy, Although buoyant, the base of the structure is held at the desired depth by an anchoring system. The scheme is moored in deep water (i. e. depth >50m) by concrete weights attached to mooring wires. The outputs from the various buoys in offshore wave-wind farm would then be gathered together at a central powerhouse for onward transmission to the onshore, and to the grid.

The scheme under consideration consists of rectangular (500m× 800m) array of 956 buoys. Areas of the continental shelf that are considered suitable for deployment of the device are near-shore/offshore waters with a sea depth of 50-200m and with relatively high waves. However, the design is at an early stage of development and there are several aspects that need further development.

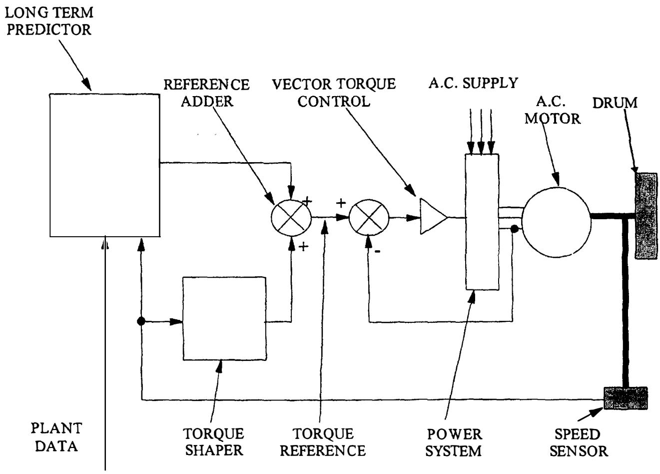

Fig.5 Outline of Electrical System Design of Wave-Wind Power Generation Device

Novel features of the wind-wave energy device

The extensive use of composites and resins as construction materials which results in reduced costs for fabrication and which are also resistant to corrosion the use of an open-lattice framework and supporting structure which minimizes wave loading on the structure and allows more wave energy to be available for power generation the use of a three dimensional array of devices various novel technical features such as the method of conversion of the vertical force resulting from the passage of a wave into a rotary force, the method of limiting horizontal forces on the blades of the wind turbine. The combination of energy generation from wind and waves improves the reliability of energy supply.

A wind-wave energy-generating scheme will consist of an array of multiple units of the device deployed offshore. Exploitable sea areas are anywhere with sufficiently energetic waves and a water depth of 50-200m within the 0°-15° trade wind zone and the 35°-75°

seasonal wind zone in either hemisphere. Estimates of average wave power capture for arrays deployed in energetic waters such as those of the UK are considerably higher than those of less energetic water such those of Korea. For example, a single 800m long array will capture <2000 kW offshore Korea compared to >4000 kW offshore UK. Similarly, an installation of six rows of 800m long will capture <5000 kW offshore Korea and >20000 kW offshore UK. Estimates of average annual output of electricity are <20 GWh offshore Korea and >50 GWh offshore UK for two rows of 800m long and 30GWh offshore Korea and >120 GWh offshore UK for six rows of 800m long. (Fig. 7 and Thorpe, 1996, 1997)

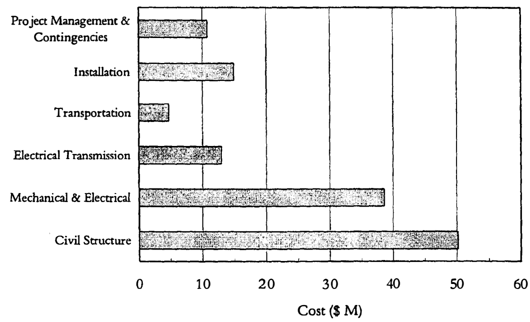

Fig.6 Summary of Capital Cost of the Wind-Wave Energy Scheme

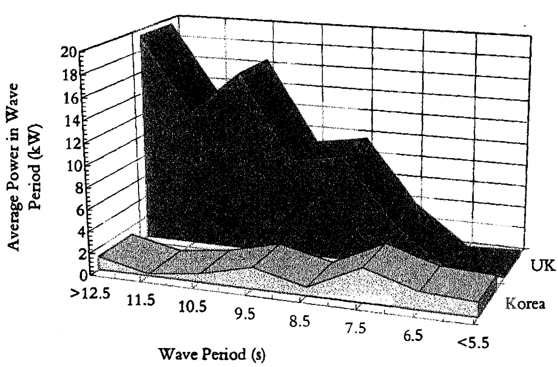

Fig.7 Comparison of the Korean and UK Wave Energy Regimes

CONCLUSION

The brief report in this paper details a novel concept for a combined wind and wave energy generation system. Studies have shown that the new design concept could offer a cheap method of producing electricity if the device is deployed in high energy offshore waters around the world.

A preliminary analysis of generating costs for an array of 956 buoys 800m long by 500m wide suggests that an optimized scheme deployed in energetic waters such as those around parts of Western Europe (see also Fig. 7) might be economically competitive with a range of

Table 1 Indicative Generation Costs for Different Renewable Energy Systems

Type of System	Location and Time	Cost of Electricity c/kWh
Solar Thermal - Parabolic Trough	New Mexico - 2020	7.5 - 11
Solar Thermal - Parabolic Dish	New Mexico - 2020	6 - 10
Solar Thermal - Central Receiver	New Mexico - 2020	5 - 9
Photovoltaic	New Mexico - 2020	5 - 14
Photovoltaic - Thin Film	New Mexico - 2020	6 - 10
Photovoltaic - Multiple Thin Film	New Mexico - 2020	4 - 7
Wind Turbine (6-9 m/s wind)	1995	3.6 - 6.5
Wind Turbine (6-9 m/s wind)	2000	3 - 5.5
Wind Turbine (6-9 m/s wind)	2010- 2020	2 - 4.,5
Combined wind-wave system	Korea - 1995	11 - 18
Combined wind-wave system	UK - 1995	6 - 9

other electricity generation technologies, using both conventional and renewable energy sources. Table 1 and Fig.6 provide indicative generation costs for a range of renewable energy sources and summary of capital cost of the proposed wind-wave energy scheme. Costs for electricity generation by an optimized scheme in energetic waters of the UK are expected to be in the region of 6-9 c/kWh.

Further this research work will be continuing to develop and improve the design methodology and are intending to progress to testing a prototype in the near future.

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LEGAL AND PRACTICAL CONSEQUENCES OF NOT COMPLYING WITH ISM CODE

Liang Chen

Hong Kong Polytechnic University
Hong Hum, Kowloon, Hong Kong, CHINA
cmslchen@hkpucc.polyu.edu.hk

ABSTRACT

It has been confirmed as fact now that some shipping companies could not meet the deadline set for complying with the ISM Code for 1998, though available statistics show that most parties concerned have been ISM certified. What the legal consequences would be for such failure is the question on the minds of many people concerned. This paper sets out to deal with this question by answering, amongst other things, the following questions: (i) Would such a failure amount to unseaworthiness in the conventional international bills of lading law? (ii) Would such a failure provide valid defences to marine insurers for rejecting a related claim or prompt the establishment of a new pre-condition for purchasing insurance? (iii) Would such failure deprive a shipowner's right to limit his liability under the international conventions concerned? (iv) Would such failure make the ships concerned more liable to detention at ports?

APPLICATION OF ISM

Two Deadlines

In recent months and, in fact, throughout the last year the hottest phenomenon receiving media attention was the ISM code, which is a short form for "International Management Code for the Safe Operation of Ships and for Pollution Prevention", made mandatory its formal attachment to Chapter IX of Safety of Life at Sea (SOLAS for short) as amended in 1994.

It is now more than six months after its first deadline, on 1st July, 1998, for application (according to Resolution 2 of Chapter IX of SOLAS), which requires the following types of ships to comply with what is required under the ISM code:

Passenger ships (including passenger high-speed craft regardless of gross tonnage);
Oil tankers (500 gross tons and upwards);
Chemical tankers (500 gross tons and upwards);
Bulk carriers (500 gross tons and upwards);
Cargo high speed craft (of 500 tonnage or upwards)

"Bulk carriers" here refers to those ships constructed solely for the purpose of carrying dry cargo in bulk according to a recent interpretation, of s.1.6 of SOLAS, Chapter IX, issued by IMO.(Definition of Bulk carrier under the ISM code ,1998) The other carriers designed to carry goods in bulk such as ore carriers or combination carriers will have to meet the deadline of July 1, 2002. This second deadline includes other cargo ships, such as container ships, or mobile offshore drilling units of 500 gross tonnage and above.

In Europe, however, the ISM code has already come into force with effect from July 1, 1996 for Ro-Ro ferries to and from European Union ports, largely because of *The Herald of Free Enterprise* and *The Estonia* tragedies, though this earlier enforcement is viewed by some as disregarding the international consensus about the first deadline thus adversely affecting the unprepared. (Pamborides, 1998)

Available statistics of Compliance

During the past year, various estimates about the compliance rate had been made before the deadline. The following are some of them plus those collected after the deadline.

IMO estimated before the deadline that 78% of world tonnage would meet the first deadline (ISM says 78 percent of world fleet will meet ISM code deadline, 1998). On July 1, 1998, IMO announced that 87% of all vessels concerned had gained the ISM Certificate (Recent development worldwide,1998). But for those ships actually checked by port state control inspection, which is reported to IMO, 11% were found to lack ISM certification (ISM anticlimax shipping survives its date with denting, 1998). Some typical deficiencies are reported elsewhere (PSC and ISM --- the Experts' Opinions, 1998) as , first, documents on board not fitting the ship under inspection; second, the crew not being able to identify the designated person ashore; third, manuals required were not in the working language of the crew; fourth, life saving and fire fighting equipment found deficient.

Before the deadline, it was also estimated that Korea would have 90% of its tonnage meeting the deadline, whilst all Hong Kong's ships were said to be able to meet the first deadline (See Flynn, 1998). It was also stated in the media that there should be no problems for all Australia's ships to meet the first deadline (Australia on target for Code deadline, 1998), but the statistics coming out of Tokyo MOU reveal that the Australian flag is the third poorest performer, with a detention rate of 6.9%, in the enforcement of ISM (Poor performance in ISM study, 1999).

On July 1, 1998, the U.K. Maritime and Coastguard Agency (MCA) reported that all U.K.-registered ships had been ISM certified (International safety management code enters into force,1998). It was also estimated that all China-registered shipping companies engaged in foreign trade would be certified (Chinese owners face unique challenges of ISM implementation, 1998). Intertanker also stated on 18 June, 1998 that all its members had been ISM certified (International safety management code comes into force, 1998). Lloyd's List reported on July 3, 1998 that up to 95% of the vessels concerned in Singapore were ISM compliant(Up to 95% Compliance in Singapore,1998). More doubtful is the Greek fleet which largely consists of shipowners owning one or two ships.

On the world scale, if IMO's statistics are to be believed, an 87% compliance rate is not a bleak picture. Compared with the party states to SOLAS which have a total 70% of the total tonnage, that compliance rate is still not bad at all. However, these positive statistics are not free from doubt. Two suspicions from experts (PSC and ISM – the experts' opinions, 1998) are that, first, most deficient ships are not calling at heavily-enforced ISM ports and, second, that the relevant documents are gained through inadequate procedures. As for those detained through port state control, the deficiencies remain as fundamental as prior to the ISM implementation (Hill, 1999), for which there is no reason for complacency.

LEGAL STATUS OF THE ISM CODE

All the states party to SOLAS, as amended in 1994, should comply with the ISM code, disregarding whether or not it has been incorporated into national law. If there exists some conflict between domestic laws and the ISM Code and the domestic law effectively prevails over the ISM code, the state party involved would have constituted a breach of the international convention in the amended SOLAS 1994. Most major trading states or districts in the world are party to the amended SOLAS 1994 incorporating the ISM code. Among them, is the U.K. which has also given force of law to the ISM code through Merchant Shipping (International Safety Management (ISM) Code Regulations 1998, the U.S.A. (Connaughton, 1998), People's Republic of China (Ten revisions of SOLAS effective, 1998), as well as the Hong Kong SAR through Merchant Shipping (Safety) (Safety Management) Regulation, 1998.

GENERAL REQUIREMENTS OF THE ISM CODE

The main purpose of the ISM Code is to ensure safety at sea in terms of preventing human injury or loss of life and pollution to the marine environment. It establishes international standards of safe management and operation of ships and marine pollution prevention. In broad terms, under the ISM Code shipowners are left to design a way as to how to achieve such a standard. So, it requires shipowners to develop and document a safety management system (See S.1.4 of ISM Code) which is intended to ensure that equipment has been properly tested, maintained, staff properly trained in its use and deficiencies in the system promptly identified and rectified, or in other words, to ensure good practice. .

Shipowners who have been found, through auditing by flag states' own administrative organs, (e.g. U.K.'s Marine Safety Agency or P.R. China's China Classification Society) or through its authorised bodies (other than those authorised by the shipowners) such as some specific classification societies, to have complied with the requirements of the ISM code will be issued with a Document of Compliance (DOC). Any ships under the management of such certified shipowners will be issued a Safety Management Certificate (SMC) if a separate on-board auditing has certified the shipowner's compliance with the ISM code. It is still a moot point whether or not a classification society should be responsible for the loss to a third party such as cargo owners for issuing a certificate wrongly (Nicolas H., 1995).

By virtue of Regulation 4 of Chapter IX of SOLAS, the flagstate administration is responsible for issuing DOC and SMC. Under Regulation 6 of Chapter IX of SOLAS, the flagstate administration is also responsible for carrying out periodic checking of the effective operation of the safety management systems, as DOC must be verified annually and SMC must be verified every two or three years, although both DOC and SMC are valid for five years. On the other hand, the company should also carry out internal auditing to check the effective operation of ISM by both offices ashore and on board ships. One other special feature of ISM is that, a designated person should be appointed to link the management on board and the management ashore through an accident or non-conformities reporting system.

But, as we will see below, the misconduct of such a designated person may or may not be imputed to the alter ego of a shipping company, depending upon the situations.

If the management of a ship is wholly delegated to a third party management company, which may be a cost-saving route for small shipowning companies, ISM requires that the third party's details be lodged with the flagstate authority who will be responsible for issuing a DOC to that third party. If only part of the management such as manning is delegated to a ship management company, the shipowner should also ensure that the ship management company complies with the ISM code. In either of the above instances, the shipowner cannot escape the responsibility of non-compliance of ISM by the ship management company or by the ships under the management of such a ship management company in relation to third party claimants. That is because the managing company is the shipowner's agent, whose acts should normally bind the shipowners. However it is provided by S.1.1.2 of the ISM code that the company entrusted with the management is assumed to have "agreed to take over all the duties and responsibility imposed by the Code". The shipowner may choose to insert an indemnity clause in the ship management contract with that third party ship management company, ensuring he be indemnified in the case of non-compliance caused by the fault of the third party management company. If a ship concerned is bareboat chartered to a company registered in another state and thus the ship so chartered may be entitled to register under this state's flag, the administrative duties relating to the ISM code will be passed to this flagstate.

In the light of the above, it can be summed up that the mission of the ISM code is to identify substandard ships, shipowners and managers.

RELATIONSHIPS WITH OTHER QUALITY ASSURANCE STANDARDS OR RULES

The standards STCW, ISO9000 and ISO14001 (or 14000) (Ven, 1998) and ISMA (ISMA wins out with softly, softly approach on standards, 1998) are designed to achieve quality assurance for one purpose or another, among them, STCW and ISO9000 are the most famous and important and merit more discussion here.

Relationship With STCW (Seafarers Training Certificate of Watchkeeping 1978 Amended In 1995)

STCW and the ISM code are the two important quality assurance rules in the shipping field, the latter ensures that there is a safety management system ashore and onboard, while the former is intended to ensure those on board are competent in executing all the safety operating procedures for the voyage including those required under the ISM code. But competence of the personnel on board in executing the safety management system is also required under the ISM code. So in this respect, STCW and ISM overlap (Bievre, 1998). Given this overlap, it is more cost-effective if the audit for both ISM code and STCW can be carried out simultaneously.

Relationships With ISO (Intentional Standard Organisation)

ISM and ISO are similar in the sense they are all rules designed to ensure that there is a quality procedure or system in place. Yet there are some important differences between them, such as:

(1) ISO is not mandatory while the ISM code is;
(2) ISO is applicable to any company, while ISM is only applicable to shipping companies;
(3) ISO leaves an individual manager to set up its own objectives and targets, while the ISM code provides for an international standard for safety management and operation of ships at sea and prevention of marine environmental pollution which must be observed by the managers.

Given the above differences, it cannot be said that ISM code can be substituted for ISO. ISO is in fact more established and better known to the governments or potential clients, and is usually a pre-requisite for gaining new business. As the ISM and ISO are substantially based upon similar principles, compliance with one of them will be strong evidence of compliance of the other. So it is also more economical to co-ordinate audits for both ISM and ISO.

NON-COMPLIANCE WITH ISM CODE

Non-compliance normally takes two forms: at present and in the near future, non-compliance with the ISM code will take the form of not acquiring the relevant DOC and SMC by the parties concerned, or in other words, there is no satisfactory Safety Management System in place. The second form of non-compliance occurs when the SMS is not effective or is wrongly executed. Letting the non-compliant parties loose without penalty is what is to be avoided by the ISM code. The following are some legal and practical consequences of such non-compliance.

CONSEQUENCE OF NON-COMPLIANCE

Under Bills of Lading

As to seaworthiness

Any evidence based upon the paper trail indicating non-compliance with what is required under the ISM code could be used to establish want of due diligence in making the ship seaworthy under the Hague or Hague–Visby Rules, to either of which most bills of lading are subject. In other words, the ISM code will provide a new barometer about the standard of seaworthiness.

As seaworthiness obligation is non-delegable under Hague or Hague-Visby Rules, the closer link between on-board management and management ashore under ISM code would not expose carrier to more risks of breaching seaworthiness obligation. Such non-compliance may also reinforce claims of improper manning of ships and ships not possessing proper certificates, both of which are examples of unseaworthiness. The position with respect to seaworthiness under Hamburg Rules is similar to that under the Hague -Visby Rules, though there is no independent seaworthiness concept under them. The Y2k problem could also be regarded as a ‘seaworthy’ problem subject to port state control inspection.

Personal or vicarious liability of carriers in navigation or management of ships

As on-board management is more closely related to management ashore, especially through the designated person, some otherwise personal errors of crew in navigation or management of ships may, under the ISM code, be attributed to the fault of the management ashore, or more exactly , to the fault of the alter ago of the ship owners or ship operators. If this could be attributed to the fault of the management ashore existing before the start of the voyage, the ship may be regarded as unseaworthy.

Right to rely upon package or kilo limitations

If non-compliance of the ISM code is intentional such as knowingly not acquiring the ISM certificate in time it may jeopardise the carrier's right to enjoy the benefits of package or kilo limitations under Hague or Hague-Visby Rules.

If the safety management system is not properly executed, the wilful misconduct of the alter ago of the shipowner in relation to the non-compliance must be found before the shipowner can be deprived of his right to enjoy the benefits of package or kilo limitations. In such a case, the personal wilful misconduct of the designated person, for example, in not reporting any non-conformity (See s.10.2 of ISM Code) should not be regarded as the wilful misconduct of the alter ago of the shipping company, unless the constitution of a shipping company has provided that the designated person is the legal representative of such a shipping company.

Under Charter Parties

Similar situations occur as those under bills of lading if charter parties adopt similar terms as the Hague or Hague-Visby Rules. If the strict seaworthiness obligation was implied under the charter parties, the ISM code would not make the carrier's liability stricter. A special indemnity clause as that designed by BIMCO recently may be inserted into the charter party to ensure that the charterer may be indemnified by the shipowner if there is any loss or damage to the charterer caused by non-compliance of the ISM code by the shipowner.

A non-ISM compliant ship may find that there are fewer chances for it to be let out in the charter market.

Under Marine Insurance

Non-ISM compliance by hull assured under a voyage policy may amount to breach of seaworthiness warranty for the purpose of s.39 (1) of MIA 1906 under English law or of MIO 1966 under Hong Kong law.

In a time policy, if a hull assured knowingly sends a non-ISM-compliant ship to sea it may also expose him to the liability for the loss caused by such non-compliance in accordance with s.39 (5) of MIA 1906. As mentioned previously, for the purpose of marine insurance, the knowledge of the designated person about the non-ISM compliance may not be treated as the knowledge of the hull assured, unless the constitution of the company of the hull assured regards such a designated person as the legal representative of the company.

In the hull insurance market, theoretically speaking, it would be very risky for an insurer to agree to insure a non-ISM-accredited ship. As the ISM code will be incorporated into many state parties' domestic law, insuring an non ISM-accredited ship may be illegal such as a breach of warranty of legality under M.I.A. 1906 in English law or at least an unaccepted risk (Donaldson, 1998). The same should be true of liability insurance with P& I clubs (Club move on ISM code, 1997) which in fact would make ISM compliance a condition (Turn of the ISM screw, Skuld makes non-compliance harder, 1998) or an uninsured peril (see Levy, 1998). Some clubs, such as Skuld, makes the ISM Compliant status a material circumstance which needs to be disclosed before the entry of the club as a member (see Levy, 1998)

In some marine cargo insurance markets, it has already been established that a warranty of not knowingly putting cargo on board a non-ISM accredited ship should be inserted in cargo insurance contracts (Recent development worldwide, 1998).

It has even been suggested that, in a short term at least, the insurance premium may be reduced for those ISM-accredited ships. However, the ISM issue may be ignored or taken lightly if the insurance market is very soft (ISM code sparks debate, 1998).

Under Tonnage Limitation Regimes

As with the package or kilo limitation regimes under bills of lading subject to Hague-Visby Rules or Hamburg Rules, the question arising under ISM is whether or not the actual fault or privity or wilful misconduct of the designated person will be regarded as the wilful misconduct or actual fault or privity of the shipowner so as to deprive his right to rely upon the Tonnage Limitation Convention 1957, 1976 (and even its 1996 protocols, though not yet in force) or CLC 1992 with respect to oil pollution liability. The answer is that it depends upon whether or not under the constitution of the shipping company, the designated person is regarded as a legal representative of the shipowner company or not (see Meridian v. Securities Commission, 1995). Otherwise, the designated person should not be regarded as representing the "directing mind" of the shipping company according to ISM provisions, unless it is a very small company where it is impossible for the "directing mind" in it not to know what the designated person has known. However, under some circumstances, the directing mind of the shipowner company has been put upon inquiry , the directing mind should demand a report concerned from the designated person, otherwise, the shipowner may run the risk of being reckless or turning a blind eye to the information it should have known by making such a inquiry. This is also true of OPA 1990 where s. 2704(c) specifically provides that "gross negligence, wilful misconduct ....." of a party will deprive him the benefits of limitation under the OPA.

Related to Marine Collisions

Non-ISM compliance with the ISM code would indicate that a non-compliant ship has breached the standard of good seamanship which has been raised by the ISM code and consequently may be blamed for the collision in question. As is the case with breach of collision avoidance regulations which may provide evidence as to the negligence on the part of the regulation–breaching party, non-compliance with the ISM code may also evidence negligence on the part of the non-compliant ship.

Related to Ship Finance / Mortgagee Banks

Mortgagee banks will find the non-ISM compliant ship be in a more dangerous situation than ISM-compliant ships, because the former is more likely to be detained and lose its insurance cover. As a result, banks will probably make ISM-compliance a pre-condition for the ship to be financed. However, once a ship has been mortgaged by a bank, the bank may be hesitant to be too deeply involved in making an enquiry as to whether or not the ship has maintained its ISM status for the very reason that the bank's mortgage risk insurance may be terminated if the ship is found to be non-ISM compliant. But the dilemma exists that if it refrains from making an enquiry time and again about the ship's ISM status, the bank will be more exposed to any default in mortgage payments.

Related to Criminal Liability of Shipowners

Although the ISM code, especially Chapter IX of SOLAS, does not impose criminal liability on the ISM-non-compliant parties, when the ISM code is incorporated into domestic law of some states, breach of it could mean criminal liability for the carrier or the master or crew concerned. If loss of life results from the non-ISM compliance, the carrier/shipping company may be accused of corporate involuntary manslaughter, which is now possible in some countries including the U.K. Under English law (Merchant Shipping (International Safety management (ISM) Code Regulations, 1998) a designated person will also be subject to penalties for committing a criminal offence if he is found not to have exercised due diligence or taken reasonable precautions to avoid breaching his duties under ISM.
Under the Shipping Safety Administration Code of the People's Republic of China, which came into force on October 1, 1998 (Shipping Safety Administration Code of P. R. China, 1998), violation of the ISM code may be subject to six levels of punishment under Chapter 2: "(1) warning; (2) financial punishment; (3) temporarily withdrawal of license; (4) complete withdrawal of license; (5) ship confiscation; (6) other kinds of punishment by law and administrative regulations."

Related to Ship Registration / Flag State Control

Statistics of non-ISM compliant vessels flying certain flags will be bound to damage the reputations of those flags because it is primarily the duty of a flag state to carry out principal ISM auditing and responsibility for issuing DOC and SMC to the relevant parties or ships. To protect the reputation of certain flag states, it is likely that being ISM-certified will be a precondition for being registered with certain states.

On the other hand, the poor reputation of some flags of convenience(FOC) will make the ships flying those flags more likely to be inspected at foreign ports. As a result, FOC will find it difficult to survive in an ISM era, though some statistics suggest that the safety record of FOC registered ships (e.g. those flying the Liberia flag) may not be as bad as one thinks (FOC tag irrelevant to safety standards, 1998).

Related to Port State Control

Port state control (PSC) is a device to check the implementation of various international conventions including the ISM code by flag states so as to ensure as far as possible the uniformity of the implementation of those international conventions. Port state control is an erosion of the sovereignty of the flag states under international law including the 1982 law of the sea convention. But such erosion has long been granted by international conventions. With respect to ISM code, PSC is provided for under Chapter I n 19 and chapter IX's Regulation 19 and Chapter IX Regulation 4. Port state control is normally the subject of regional agreement in the from of a Memorandum of Understanding (MOU), which ensures the exchange of information and uniform standard of port state control, and ensures such port states put similar resources into port state control. The Paris MOU, the earliest regional agreement of this kind, is nowadays the model upon which other regions of the world base their agreements. Now there are six MOUs having been established, i.e., Paris MOU, Tokyo MOU, Vina del Mar, Caribbean MOU, Mediterranean MOU and India Ocean, whilst there is one pending MOU, i.e. West and Central African MOU (Cigarettes, Scotch and US Dollars, 1999) including the Tokyo MOU. It is submitted that a regional agreement upon PSC is better than a global regime since a regional one more effectively ensure the uniformity of regional practices , and more effectively prevent unfair competition between ports in the same region.

Port state control may be abused by corrupt inspectors or interpreted differently by different parties. It will especially be the case in respect of the ISM implementation as the ISM code is vaguely worded, thus likely giving rise to different interpretations. As MOUs increase, the number of countries entitled to port state control inspection increase. This provides more chances of varied standard of inspectors and inspection. But under the European Port State Control Directive, an unduly detained ship will be entitled to compensation and appeal against the detention if the detained ship can prove wrongful detention.

In respect of the ISM code, an inspector will first check whether or not a valid document of compliance and a safety management certificate have been acquired by the ship operator or ships under inspection; then it should be checked against the true conditions on board or ashore and corresponds to what is required or certified under the ISM code.

The inspection and detention will be carried out on a selective basis and is not pre-arranged. But even this selective inspection may give rise to port congestion. In practice, non-ISM compliant vessels but without other deficiencies found will be warned but not detained upon the first inspection at a foreign port. But such vessels cannot re-enter certain ports until being ISM certified as provided under European Port State Control Directive (EU update, 1998).

Cargo interests will definitely be affected by port state control, so it is better to insert an indemnity clause against the detention caused by port state control in the contract between cargo interests and carriers.

It is expected that most major port states as well as the U.S. Coast Guard will exercise port state control inspection strictly.

Related to Evidential Documents

The paper trail consequent upon the establishment of safety management systems under ISM will not be privileged and thus dissoluble in legal proceedings of some states including the U.K. (See Order 24, Rule 1 (1) of the Rules of the Supreme Court) so far as they are not related to the seeking of legal advice. But in the U.S.A. there exists a kind of "protective order" which prevents the disclosure of post-casualty investigations (Shaw, 1998, Connaughton, 1998).

Those dissoluble documents includes accidents reports. The paper trail should greatly aid in establishing whether or not the ISM code has been breached, but the legal costs involved in the discovery and interpretation of these documents will be greater. In order to control the legal costs, potential claimants should make sure to have a strong case before embarking upon such an expensive discovery exercise.

As to who should prove the fault or lack of the fault for the purpose of preventing or breaking the limitation under the Limitation Convention 1976, there are conflicting approaches between European civil law countries and the U.K. In the former the burden of proof is on the client against the shipowner to prove fault including non-compliance of ISM code, while in the latter, the burden of proof is on the carrier to disprove it (Shaw, 1998). On the plus side from a shipowner's point of view, the ISM documents may assist the shipowner to prove that he has done much to adhere to good practice in shipping.

CONCLUSION

To conclude, ISM accreditation will be a license to trade for shipping companies. In other words, "no code no trade". Once accredited, the story is not at an end. Any deficiencies found in the execution of safety management system would expose shipowners to greater liability by way of, for instance, losing limitation of liability and /or insurance cover.

As a relatively new law, ISM code is not free from shortcomings; so there are the following loopholes that a shipping company may exploit to justify being non-ISM compliant:

During the last few weeks before the deadline, a non-ISM-compliant shipowner might purchase an ISM-compliant ship management company, but it is doubtful whether the shipowner could escape liability in doing so, as the ship managing company is at most an agent of the shipowner. Alternatively, a non-ISM-compliant shipowner may choose to establish a new management company to shelter behind for the 90 days grace period because a shipping company need not be ISM-compliant if it does not have its management system in place for at least 90 days.

If these loopholes are to be widely exploited, there will be a good reason for an early reform of the ISM code so as to prevent those sub-standard shipping companies or ships from having an unfavourable competitive edge in the market.

Given the costs and efforts required in acquiring the ISM compliant status, one may be prompted to ask that whether the ISM certification should in some situations be transferable upon passing of ownership between two closely related management companies, though it is doubtful such transferral would be allowed between two totally separate management companies. In English law , " transmissible warranty of quality" has not yet been established (*Reeman* v. *DOT*, 1997).

For the moment, as far as I am aware, no exploitation of the above loopholes has been reported during the period of more than six months after the first deadline --- 1 July, 1998, but it does not mean that it did not or will not happen, especially in respect of second deadline in the year of 2002. .

Above all else, the ISM code will greatly enhance the safety standard of shipping, some even suggest that it may bring the safety standard of shipping much closer to that of aviation industry (Donaldson, 1998,at p. 526). Let us hope that ISM certification will really add to the creation of a safety culture rather than being just another kind of unnecessary paper work.

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CONSTRUCTION OF BREAKWATER CONSIDERING HABITAT OF DIVERSE FISHERIES ANIMALS AND PLANTS

Makoto Sami[1], Koji Mitsuhashi[1], Noboru Sakiyama[2] and Takayoshi Mishima[3]

[1]The Japanese Institute of Technology on Fishing Ports and Communities, Tokyo, JAPAN

[2] Nagasaki Prefecture Office, JAPAN

[3] Shimane Prefecture Office, JAPAN

ABSTRACT

In Japan, people are getting ever more concerned about the importance of establishing our society to enable sustainable development with less impact upon environment. Actually in the case of national land development, intensive stress is being placed on both better co-existences with nature and qualitative improvement of national land rather than just raising of economic production efficiency. Under such circumstances, some strategic factors mentioned below have been substantially taken into account in determining construction method in relation to construction of the fishing ports (e.g. construction of breakwater) as follows:

1.Formation of seaweed bed as habitat of fisheries animals and plants.

2.Stabilization of seawater exchange to prevent deterioration of habitat in closed water area.

Fishing port improvement project with these built in factors could turn into a natural harmoney oriented fishing port. This paper presents the outline of such construction method, the detailed construction plan of breakwater practically executed in order to form seaweed bed, the overview of monitoring survey, and the evaluation on its effect monitored after completion. For practical discussions, this paper deals with the details of planning for Uki fishing port and Hamada fishing port where the formation of new seaweed bed are planned to substitute for disappearing one due to reclamation and construction of breakwater. Besides, the monitoring survey in Hamada fishing port is only introduced, as Uki fishing port is not ready yet for carrying out such survey.

CONCEPT AND SCOPE OF WORK OF NATURAL HARMONY ORIENTED FISHING PORT IMPROVEMENT PROJECT

The concept of natural harmony oriented fishing port improvement project is defined as the development of the fishing port facility with function like greenhouse (seaweed bed) of seaweed which is beneficial for diverse fisheries animals and plants to maintain, conserve and create most optimum habitat. The scope of work actually required is to improve the fishing port facility in consideration of harmony with natural environment like conservation of water property and mitigation of impact upon ambient environment, etc. The work phases are preliminary survey, execution of the work and follow-up survey after completion.

Preliminary Survey

Items of preliminary survey are shown in Table-1. The principal purpose is to investigate the habitat factors and if any unsuitable conditions were found, the structure of breakwater is to be reviewed to improve such conditions.

Table-1 Basic Items on preliminary survey

Physico-chemical Survey	Biological Survey
1. Weather	8. Seaweed Bed
2. Waves	9. Reef Resources
3. Current-Tide Level	10. Ecosystem Site
4. Topography	
5. Littoral Drift	
6. Water Property	
7. Sediment-Base	

Execution of the Work

This work is to be divided into the following two aspects:

1) Promotion of seawater exchange and conservation of water quality
- Construction of breakwater with the structure itself capable of promoting seawater exchange.
- Disposal of waste water and so forth generated in the fishing port.

2) Improvement of the fishing port facility in consideration of surrounding natural environment and others.
- Construction of breakwater ,sea wall and etc. as to enable fisheries animals and plants to inhabit and propagate.
- Build-up of seashore and etc. as to diminish any impact upon natural environment.

In order to achieve above-mentioned target, the design and construction works are to be carried out taking into consideration the results of preliminary survey as well as the available technical data and technique.

Follow-up Survey After Completion

The aim of follow-up survey is to verify the advantage of the adopted structure and construction method and also to check the effect based on comparison before and after execution of the works. This contributes to accumulation of instructive construction records and valuable technical know-how. The primary objects for this survey are seaweed bed, fisheries organism (reef life), water quality, waves, luminous intensity and current.

SPECIFICALLY DESIGNED POINTS IN SURVEY FOR NATURAL HARMONY ORIENTED FISHING PORT IMPROVEMENT PROJECT

There are two cases of newly contrived technique in consideration of ambient natural environment in line with the strategy mentioned in above 2) which are from perspectives of environmental conservation and could be classified into two categories :

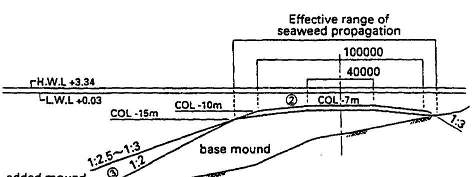
i) Creative consideration on water depth, light conditions and substrate.

ii) Creative consideration on surface substrate(protrusion angle, attaching area).

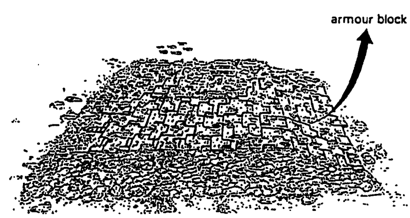
In other words, improvement of mound shape which is ensuring various water depth, proper wave motion and effective attaching base and also the detailed plan for substrateas to groove on armor block and etc.

Creative Consideration on Water Depth, Light Conditions and Substrate in Uki Fishing Port

Uki fishing port, being located in the innermost of Tachibana Bay in the southern part of Isahaya City, Nagasaki Prefecture, has been so prosperous in history owing to the rich fishing ground in the nearby water. However, in recent years, with increase of large-scale fishing vessels , the mooring basin is getting extremely narrow. Hence ,the expansion plan is needed. Nevertheless to ensure calmness in the fishing port it had become an imperative to construct the breakwater focussing in creating the new ones which could be substituting for the disappeared seaweed bed and fishing ground. In Uki fishing port, gulfweed, eisenia bicyclis and sea trumpet are selected as the primary fisheries plants. Fig.-1 shows the examples of rising elevation of the sea bottom to ensure the light volume and also improving attaching substrate on sandy bottom. The distribution of large-scale seaweed is deeply affected by water depth, light volume, wave conditions, current, sediment and certainty of substrate, etc. as shown in Table-2.



(a) Submarine level-up to secure the light volume required



(b) Improvement of attaching substratum at sandy submarine

Fig.-1 Artifitial formation technologies of seaweed bed

Consequently the technique as per Fig.-1 is evaluated to be more effective for formation or restoration of seaweed bed and was adopted for Uki fishing port improvement plan. Further, the cross section of the breakwater was examined taking into account the following points based on the results of preliminary survey;

a. Certainty of wave motion for growing of seaweed.
b. Attaching substrate with exceedingly uneven and complicated surface.
c. Formation of a variety of seaweed bed (Supply of various kind of habitat with individually different water depth, luminous intensity and velocity)

Table 2. Habitat Factors

Habitat Factor	Type of Seaweed Bed: Gulfweed	Type of Seaweed Bed: Eisenia bicyclis-sea trumpet, etc.
Water Depth	Less than 10m	Less than 20m
Light Conditions (lower limit)		1% of sea surface
Substrate (protrusion angle) (attaching area) (Height from sand surface)		More than 90° More than 300cm² More than 50cm
Seed Supply (Maturity Period)	Spring, Autumn	Autumn
Other	Water temperature, salt, food harm, competition, etc.	

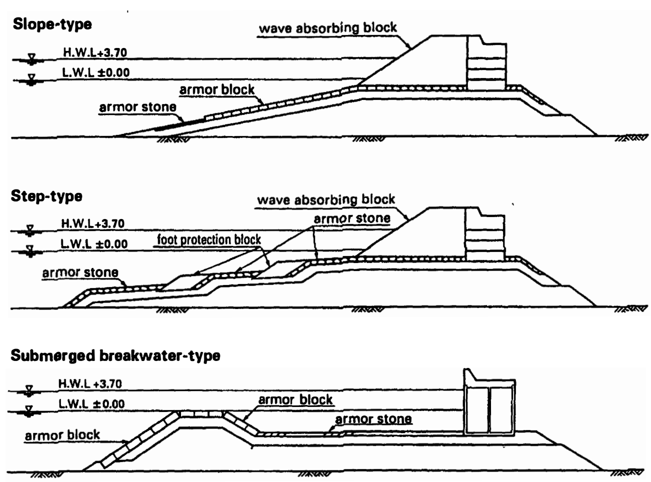


Fig.-2 Comparison of Various Breakwater Sections

As a result, as shown in Fig.-2, the comparison study on cross sections was made among 3 types of breakwater; i.e. , slope type, step type and submerged breakwater type. After compared, step type breakwater was selected .

Creative Consideration on Substrate Surface (Protrusion Angle, Attaching Area) in Hamada Fishing Port

Hamada fishing port is located in the western part of Shimane Prefecture and being ranked within fifteenth in its landed quantity. Sedogashima district in this fishing port area has been promoted as the base for high-level coastal fisheries controlled for resource management. The amenity-oriented breakwater and seawall under planning are to be of the structure with artificial reef in offshore side for wave control. The site for creation of seaweed bed is to cover the extent from artificial reef to the mound in offshore side of the breakwater and seawall. This artificial reef portion is part of the structure with no natural stone but armor block because of wave height in offshore side being approximately 8 m. Thus some design was contrived to create a specific habitat to enable seaweed and valuable fisheries species to attach easily. The solution is to have armor block (concrete), where an effective added function can be achieved and use of steel frame which is other than concrete material for formation of seaweed bed in fish reef. From past experience additional function of armor block is grooving and fowd effective way for propagation. There are 3 types of groove as shown in Fig.-3. They are designed for individual fisheries species where different type of groove is to be applied depending on site conditions provided that the mixing ratio is 50 % in site where the execution is based on block with groove. This ratio is determined by considering the relationship between habitat density and bait stocking area. Finally the steel frame , the required design of cross section is to be carried out in accordance with the design criteria set up through the experiment.Fig.-5 shows the standard cross section.

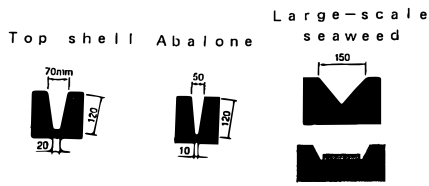


Fig.-3 Various groove and shape for life

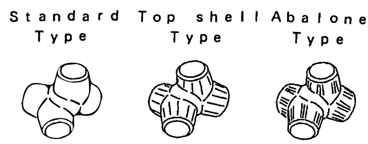


Fig.-4 Wave absorbing block (Sea Lock)

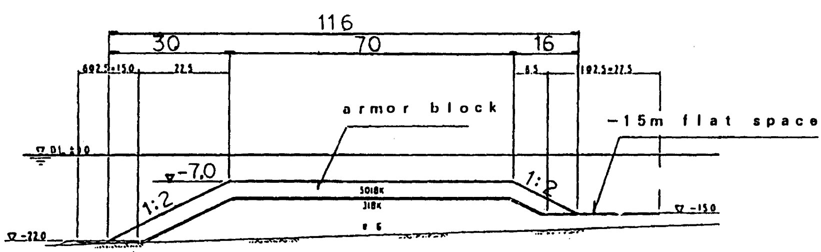


Fig.-5 Artificial Reef Sections

DETAILS OF MONITORING SURVEY IN HAMADA FISHING PORT

The monitoring survey in Hamada fishing port commenced from artificial reef partially executed and completed. In connection with this survey, overview, evaluation criteria and survey results are elucidated as below:

Overview and goal of monitoring survey

The characteristics of monitoring surveys are showing ;

(1) that propagation effect of objective fisheries animals (abalone, top shell) are verified through visual observation and framing survey on organism attaching on artificial reef and fish shoaling around artificial reef.

(2) the change by time and desirable development direction of ecosystem on artificial reef is evaluated by study on similarity against the most optimum habitat in the surrounding area through comparison of the survey data in the ambient coast before execution of the works. This is by the application of the parameters such as biomass ,(propagation effect of fisheries valuable species, formation effect of seaweed bed) diversity of species, balance of food chain pyramid and similarity based on Cluster analysis method.

Fig.-6 shows an overview of monitoring survey.

Details and results of survey

Survey stations

The survey stations were provided on Lines 1 ~ 6 as shown in Fig.-7. Survey Lines 1,2 are for the site where the armor blocks without groove were supplied (executed in December, 1995)and Lines 3,4 are for the site where the armor blocks with groove for top shell (executed in September ,1996). For these 4 Lines, 3 stationswere set up at 5 m interval with water depth of - 5 m ,10m and 15m due to water depth of the crest and apron of submerged breakwater being 5.0m and15.0m respectively. Lines 5,6 are for the site where the armor blocks with groove for top shell were used (executed in September , 1997) and 4 stations were selected at water depth of 3m,5m,10m and 15m as the water depth of the crest at this site being 3m.

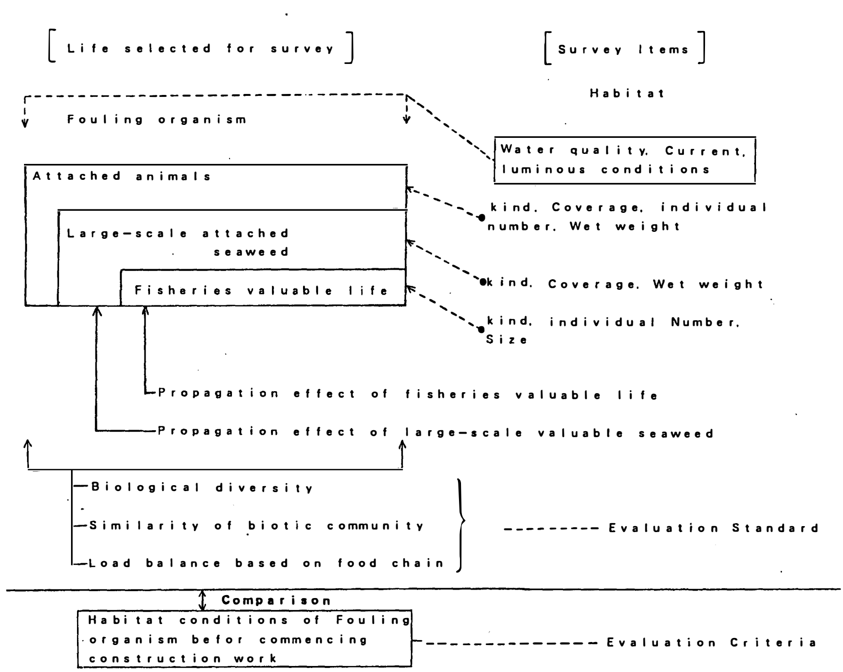


Fig.-6 Conceptual Diagram on Evaluation for Monitoring Survey

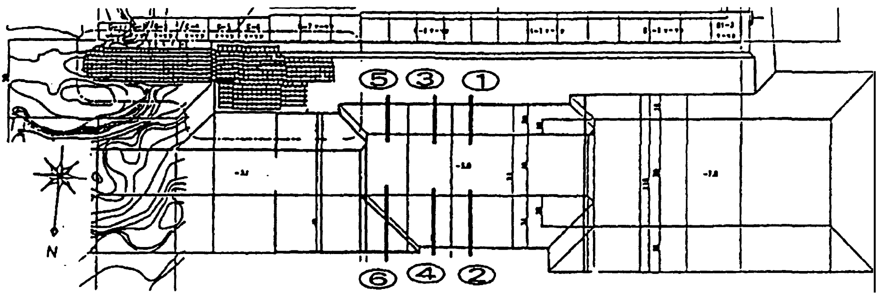


Fig.-7 Layout plan of survey lines

Items of survey

Items of survey are shown in Table-3.

Table-3 Object and items for survey

Classification	**Object**	**Method**	**Items**				
Water Measurement			Water temp., salt DO SS				
Biological Survey			Kind	Coverage	No. of Individual	Wet weight	Size
Visual Observation	Large-scale Seaweed	Figuring Measuring			⑨		⑨
	Attached Seaweed	50x50cm frame	⑨	⑨			
	Attached animal		⑨	⑨			
	Nekton	Figuring	⑨		⑨		
	Indicator organism	Figuring, Measuring	⑨		⑨		⑨
Framing	Attached seaweed	30x30cm frame	⑨			⑨	
	Attached animal		⑨		⑨	⑨	

Seasons for survey

The monitoring survey was carried out during the season where biomass of indicator organism (top shell, abalone) and large-scale seaweed(Kurome) one of the good feed remains in high level. The maximum biomass season was assumed as per Fig.-8, from experience in Shimane Prefecture.

Month	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**
Top Shell		Max										
Abalone									Max			
Kurome	Max											
Survey Seasons		⑨			⑨				⑨			

Fig.-8 Seasons for max. biomass of indicator organism and survey

The monitoring was planned to be conducted in spring, summer, and winter, one time in each season. However, in 1997, the monitoring was performed only in summer (August) and winter (December).

Comparison

The monitoring is to be compared with the results of four seasons survey conducted as preliminary survey in October and December in 1995 and in March and July in 1996. The preliminary survey was conducted at 8 Lines in the natural coast and the surrounding area of the existing structures. Referring to these results, it is considered better to reach the Line conditions, which is deemed best out of 8 Lines.

Survey results

The survey results at this stage show that the shoaling effect of fisheries valuable species and can be verified through comparison, by diving visual observation, counting on attached top shell in habitat individual number between armor blocks with groove and armor blocks

Table 4. Dimensions of Armor Block

Block Name	**Sea-Lock B 50-t Type**		**Tetrapod Type (ref.)**
Items	**Value**	**Others**	**Value**
Surface Area	42.25 m^2	---------	25.19 m^2
No. of unit per 1m^2 if slope	0.12 unit	Void ratio 50%	---------
Surface area per 1m^2 of slope	5.43 m^2	45.25 x 0.12	---------
Groove length (average)	1.1 m	---------	1.4 m
No. of grooves	18	---------	13
Total length of groove	19.8 m	1.1 x 18	25.2 m

without groove respectively. Apart from the actual site comparison ,the shoaling test data on wave dissipating blocks (Tetra pod type) with groove in Kyoto Marine Center also carried out. Table -4 shows the dimensions of Tetra pod type and Sealock B-50t type, which is being, use in Hamada fishing port.

Table-5 shows habitat density of top shell. This value is the average value figured out from in habitat individual number of top shell on 5 wave-dissipating blocks at each survey station.

Table-5 Habitat density of Top-shell (NunberUnit)

Classification	**Block Name**	**Survey Season**	**Without Groove**	**With Groove**
This Survey	Sea Lock Type	Summer	1.8	7.4
		Winter	5.4	23.3
Kyoto Prefecture	Tetrapod Type	---------	1.7	16.7

CONCLUSION

Out of natural harmony oriented fishing port improvement projects, the verification on its effect by means of monitoring survey has been actually conducted in quite a few cases. As referring to the results of monitoring in Hamada fishing port , habitat density of top shell on the blocks with groove is 4 times that on the blocks without groove. Hence ,series of future monitoring will verify any further expected effect of different type of groove and artificial reef as fish reef as well as seaweed bed. The evaluation on creation of natural ecosystem under planning this time will be a milestone for future development of technology.

The subjects for future discussion will be as follows :

a. Development of monitoring technology

It is a question mark whether the technology of natural harmony oriented fishing port improvement project with one verification from a viewpoint of its effect in a specific site will be applicable or not to other sites with different conditions. However, monitoring items should be standardized and monitoring technique should be also improved .

b. Evaluation criteria for creation plan of ecosystem

This time the evaluation was made taking into account diversity of species, balance of food chain pyramid and similarity against natural coast by Cluster analysis. However, evaluation criteria on habitat environment should be further researched.

c. Necessity of feed-back of information

The cross section of breakwater should be designed to meet such habitat factors and other local conditions which may peculiar to other region. Therefore, it is deemed desirable that the monitoring results should be taken in the practical work plan.

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CHINA'S MARINE ECONOMIC DEVELOPMENT

Hongmei Xin

State Oceanic Administration
Beijing, CHINA
soadst@public.east.cn.net

ABSTRACT

China's ocean economy has been developing very rapidly since the 1980s. This paper introduces the condition and characteristics of China's economic development as summarized from the most recent government reports on this subject. It also discusses the reasons for the fast increase, and analyzes the key issues existing in the development and the potential obstructions of the ocean economic development. It is concluded that China should abide by the principles of coordinated and sustainable development, rationally exploit and utilize marine resources, reinforce oceanographic scientific and technological research and pay more attention to environmental protection so as to improve the overall benefits and assure the sustainable and steady development of the marine economy.

INTRODUCTION

China's marine industries keep a high-level developing posture from 1980s. The increase rate of marine economy was about 17 % in 1980s. It is above 20% in the 1990s while the increase rate of the national economy is about 12%. In 1996, the total output value of major marine industries reached 285.5 billion yuan. The national economy of the coastal cities and counties supported by marine economy has grown steadily, its Gross Domestic Product (GDP) amounting to 1846.1 billion yuan in 1996, which occupies 48.4% of the GDP of the entire coastal region. It's predicted that the output of marine industries will probably surmount 500 billion yuan RMB by the year 2000. The increase rate will not be below 15%. Marine economy has played more and more important role in the national economy so that it was taken as one of the seven new economic growth spot by the government in 1998.

Table. 1 Gross output value of major marine industries(100 million yuan)

Year	1990	1991	1992	1993	1994	1995	1996
Output	439	531	756	979	1707	2464	2855

THE CHARACTERISTICS OF MARINE ECONOMIC DEVELOPMENT

The output value of the traditional ocean industries which have developed in the 1960s has been increasing steadily with the progress of science and technology. Fisheries (including aquaculture) have been always the biggest industry in China so far. The output of marine mariculture is so high that FAO claims China has made great contribution to the fishery sustainable development. The production of sea salt has occupied 66.5% of the total output of crude salt.

Table 2. Output value of the traditional ocean industries(100 million yuan)

Year	1990	1995	1996
Fisheries	248	1177	1445
Maritime Transport	99	582	541
Sea Salt	21	48	43

The Output Value of Modern Industries Climbs Sharply

Modern industries mainly include offshore oil and natural gas and coastal tourism. The coastal tourism becomes the second biggest ocean industry. The offshore oil and natural gas develops most rapidly among the entire marine industries. There are nearly 100 kinds of health protection products; ocean medicine manufacture industry has a bright future.

Table 3. Output value of the modern ocean industries(100 million yuan)

Year	1990	1995	1996
Coastal Tourism	58	365	420
Offshore Oil and Natural Gas	11	123	213

Oceanic High Technology Industries are Forming

For example, the seawater desalination industry has reached the practical stage, the economic output is 0.2 billion yuan or so per year. The oceanic energy technology has made a breakthrough progress and is shaping its industry.

Generally, China's marine economy has been formed basically. The industry structure is gradually tending to be rational, and the gross output of major marine industries is increasing year by year. Ocean economy will still keep high speed in a relatively long period.

THE REASONS FOR THE HIGH INCREASE SPEED OF THE MARINE ECONOMY

Plentiful Natural Resource Base

China has a mainland coastline of more than 18,000 km. There are more than 5000 islands in China's territorial waters. The hinterland is vast and wide. According to the United Nations Convention on the Law of the Sea, the continental shelf and exclusive economic zone under the jurisdiction of Chinese government are vast. The shallow sea areas reach 124,000 square kilometers. About 20,278 species of sea creatures have been verified. And it's also rich in oil and gas resources, marine tourism and ocean energy, etc.

More Proper Policies Assurance

During the time of ocean development especially in 1990s, the government has made more policies, laws and decrees than before. In 1994, China Ocean Agenda 21 was formulated, and ocean was regarded as the eighth field of the national high and new technology programs. In 1996, some related Chinese ministries put forward the plan that "develop the ocean by relying on science and education" in order to enhance the contribution of science and education to the marine economy and promote it to develop steadily. So the government of coastal areas and all sides of the society to join in the plan, which forms a new ocean development situation by reliance on science and education.

Better Social, Economic Condition

Since the opening up to the world, China has been one of the most rapid countries worldwide on national economy growth. The coastal region has attracted a lot of funds, the market is prosperous, the economy of the coastal region develops rapidly. That provides a better social, economic condition for ocean development.

Strengthened Scientific and Technological Power

In 1996, there are 109 science and research institutes, 12,578 research personnel of which 27% is senior scientists. A lot of scientific and research results have been achieved and some applied technologies have been gradually put into productivity, that has promoted economic growth. In addition, the public consciousness of developing ocean by dependence on science and education has been improved.

KEY ISSUES AND SUGGESTIONS

Due to the reform and opening up policy, China's coastal region has become most active in economic development. The coastal region covers 15 percent of the total land area of the nation's territory, has 40 percent of the nation's population, but contributes 60 percent of the total social output value of the whole nation. So the role of ocean economy can't be underestimated. How to develop the economy of the coastal region is not only the issue that relates to the coastal regions itself, but also will influence greatly the whole national economic development, and the promotion of the comprehensive national capability. However the conflicts among resource, environment and economy are increasingly serious with the economic development of coastal region and the increasing intensity of the modern marine development.

Marine Environmental Pollution

Because the coastal regions are still in the primary period of industrialization, ocean environment pollution is increasingly serious, ocean disasters happen more and more frequently, ecosystem is deteriorating. According to statistics, the total amount of industrial sewage directly discharged into the sea is 0.63 billion tons in 1996, 21.7% up from that in the previous years. The increase amount of sewage and solid wastes discharged into the coastal waters enlarged the extent of pollution in the nearshore waters. The pollution rate of the coastal region is higher than the nation's average. Red tide events and oil spills make direct economic losses of 1 billion yuan per year. The indirect loss amount of marine tourist and sea salt industries etc. reaches several billion yuan. The red tide event, which occurred in Guodong province from October last year to March this year, resulted in 100 million yuan. Environment pollution resulted in offshore movement of larval and spawning grounds. The main commercial fish kinds turned to be shorter-period, younger-aged and smaller. The deterioration of local ecological environments has directly threatened the commercial output value, and even the health of the people in coastal areas and the daily life. Generally, the marine environmental quality and the coastal economic and social development is not in a better balance.

It is necessary to further improve the management system and legal work for marine environmental protection. It also should further improve the education in marine environmental protection so as to raise the public awareness of marine environmental protection. The most important thing is to take effective measures to strictly control the total amount by land-based pollutant discharged into the sea and the land-based and sea-based activities which resulted in marine environmental degradation. That is an active and strategic choice of coastal regional economic development to promote the national economic increase.

Marine Resource Exploitation

In recent years, as marine development activities have been developing in breadth and depth, the marine resources is faced with grim situation: the resource development is not all reasonable as a whole, and comprehensive benefit is not high. Management system is scattered, policies were formulated by different department in some areas, the waste of resources is serious. Unreasonably, marine and coastal engineering accelerates the coastal erosion and coastal environmental changes. The environmental quality is degraded and the ecosystem is out of balance. For example the overfishing in the offshore fishing grounds in previous yeas has nearly resulted in the disappearance of the traditional fishery species.

Due to China's per capita marine resource possession is relatively small and China stays in period of developing rapidly, the urgent tasks is to reasonably protect, develop and utilize marine resources, so as to satisfy the need of the social economic sustainable development. It also is necessary to find out a new way to use resource repeatedly, strengthen the integrated management, and enhance the legal work of development of coastal and offshore land, reduce the rate of resource damage. So far, China has formulated the national marine development and marine functional zoning plans, they are the basis and one of the important means to enable China's marine economy to develop in a sustained, steady rapid and coordinated way, which must always be adjusted and improved.

Science and Technology

China has done a lot of research work in marine resource and environment survey and achieve a lot of notable results. China's ocean development is still in a primary stage, traditional industries play main roles up to now, the contributions of science and technology to industries in not enough high. Compared with advanced countries, China has a long way to go in the ocean development and the progress of science and technology. The marine scientific and technological stuffs and their overall level still can't satisfy the need of marine economic development and application. Century 21 is an era that advanced science and technology, qualified scientists and technicians compete sharply. The development of marine economy and the progress of society basically depend on raising the level of science and technology and the quality of marine products.

At present, Chinese government has proposed "develop ocean depend on science and technology " to raise the contributions of science and technology to the marine industries and to the economic development, which also should be carried out properly.

CONCLUSION

21st century is an era of ocean, China is a major marine country which has plentiful marine resources, so China is confronted with great challenges and opportunities in ocean development. China should abide by the principles of coordinated and sustainable development, rationally exploit and utilize marine resources, reinforce oceanographic science technology research and enhance environmental protection so as to improve the overall benefits and assure the sustainable and steady development of the marine economy.

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SEDIMENT FAUNA, FISHERIES CATCHES AND LAND EARNING FROM THE KOREAN TIDAL FLAT, KOREA

Chul-Hwan Koh

Department of Oceanography, Seoul National University
Seoul, KOREA
kohch@plaza.snu.ac.kr

ABSTRACT

This paper reports that the coastal use of the Korean west sea has been concentrated rather in the mass land earning than the nature conservation. Faunal records, secondary production of bivalves and fisheries catches are described to emphasis the ecological importance of the tidal flat. Studies on sediment fauna and annual production of bivalves inhabiting tidal flats were carried out at 167 stations of 8 localities along the whole coast from 1989 to 1997. A total of 94 taxa were identified. Dominant species were: *Heteromastus* sp., *Umbonium thomasi, Latenula* cf. *limicola* and *Lingula anatina.* The high biomass of edible bivalves at different localities were shown by *Sinonovacula constricta* (2,678 g TWW m^{-2}, Total Wet Weight including the shell), *Ruditapes philippinarum* (1,221 g TWW m^{-2}) and *Mactra veneriformis* (629 g TWW m^{-2}). Annual production of those species calculated from the growth rate and biomass were 1,358, 1,635, and 2,998 g TWW m^{-2}, respectively. Important fisheries catches were molluscs. The areal dimension of land earning from the tidal flat was recorded as 405 km^2 from 1917 to 1945, 620 km^2 from 1946 to 1994 and 764 km^2 including the project in progress. Those deterioration threatens the coastal ecosystem and, therefore, a change in policy of land earning is needed.

INTRODUCTION

The Korean (South) West Sea located in the eastern Yellow Sea belongs to a macrotidal regime where the tidal height reaches up to 10 m on the coast in the north. The high tidal ranges and the gentle bottom slope produce broad tidal flats which rival those on the North Sea coast. Tidal flats are developed to about 10 km wide in many places and occupies an area of about 2,800 km^2. The coast is one of the rias with dented geomorphology.

The coastal use on the West Sea has mostly been directed to a reclamation of tidal flats by separating them from the sea by sea walls. Dikes has been constructed at the mouths of bays if there a wedge-shaped tidal flat is developed. Land earning is the prime interest and, therefore, tidal flats have frequently been diked and land-filled.

This study is aimed primarily to present biological data to give an overview of sediment infauna occurring on the Korean tidal flat. Biological resources are evaluated based on data of secondary production estimated for edible bivalves. Statistics on fisheries catches are also included to demonstrate the high productivity of the Korean tidal flats. By referring the historic records of the tidal flat reclamation, we have discussed the future strategies of an wise use of the Korean coast. It was of our question how political economy and collective action concerning the utilization of such unique ecosystem should be structured in the future.

MATERIALS & METHODS

Field surveys has been carried out at 167 stations assigned to different tidal flats from the north to the south along the whole west coast (Fig. 1). We named the surveyed tidal flats by the villages located nearby as Youngjongdo, Songdo, Panweol, Hwasung, Daesan, Kunsan, Kimje, Buan tidal flat.

Subjects which were concentrated during the surveys were the occurrence of sediment fauna by species and individual numbers, and the biomass and seasonal growth edible bivalves. As an environmental factor, grain size of the sediment has been analyzed at every stations. Occurrence of the tidal flat animal was investigated at 8 localities along the coast. A box core of 0.1 x 0.2 x 0.3 m (surface area: 0.02 m^2) was mostly used to collect the benthic animal. The collected sediments were washed on a 1 mm mesh sized sieve, and the animals retained were fixed with 10 % formalin solution in seawater. After identification and counting the individuals in the laboratory, individual numbers were converted to the numbers per 1 m^2.

Object animals for the production studies were *Mactra veneriformis* common to the sand flat, and *Sinonovacula constricta*, a typical bivalve on the mud flat, and *Ruditapes philippinarum* frequently found on silty to sandy sediments. The production study of *M. veneriformis* was conducted on the Songdo tidal flat at 17 occasions from March 1989 to September 1990. The bivalve *M. veneriformis* was collected from ten 0.5 x 0.5 m quadrates randomly laid on the lower intertidal. The shell length and flesh dry weight of more than 100 individuals was measured at every survey. A multiplication of the individual dry weight with individual numbers counted from the sample quadrates produced the biomass (*B*) which was applied to an estimation of the secondary production. The production, *P*, was then calculated by a multiplication of the relative growth rate, *G*, with the biomass (Ricker, 1946). The production was estimated for every age class obtained by counting the growth ring. The annual yield of *M. veneriformis* was the sum of the production calculated for every age class.

The study on the production of *S. constricta* was carried out on the Hwasung mud flat for one year from September 1992. The production biology of the Manila clam, *R. philippinarum*, was studied on the Daesan tidal flat on 13 occasions from September 1991 to 1992 at monthly intervals.

RESULTS

Type of sediments

The predominance of sand and silty sand sediments was observed on the Songdo tidal flat, while the finer silts were typical of the Yongjongdo tidal flat. The majority of the Hwasung tidal flat was characterized by silts, whereas the sediments on Panweol tidal flats contained higher percentage of clay. The broadest tidal flat around Kunsan, Kimje and Buan were composed of sand to silt sediments.

In brief, the tidal flat of Yeongjongdo, Panweol and Hwasung belonged to silt-mud flat, while Songdo, Kunsan, Kimje and Buan tidal flats could be described as sandy-silt to sand flat.

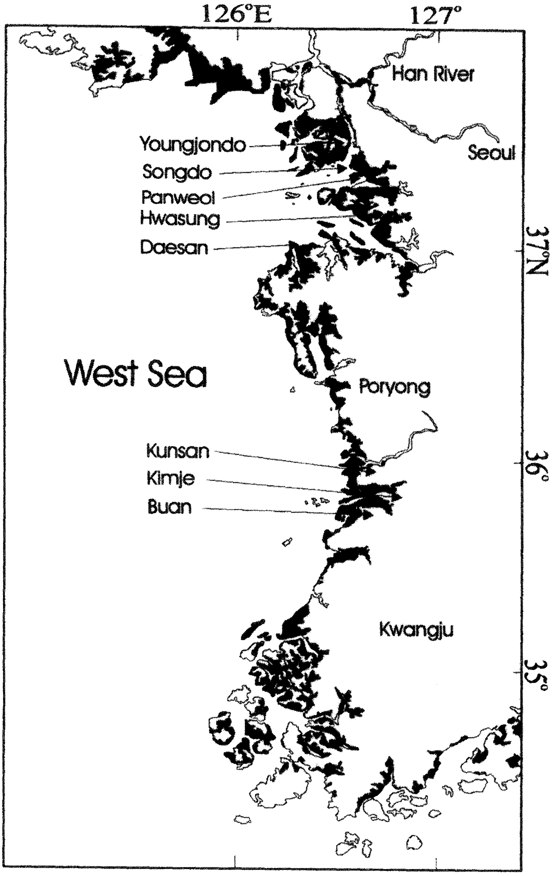

Fig. 1. Distribution of the Korean (South) tidal flat. Areal dimension is estimated as about 2,810 km^2. Tidal flats located in the northern part is broader due to the high tidal range (up to 9 m). Sediment fauna was investigated at 8 tidal flats marked by arrow.

Among the total of 167 stations, silty sand (23.6%), sandy silt (24.2%) and silt faces (23.6%) were predominated and then the sand face (15.8) followed. Less mud faces were found (7.3%). Most stations were characterized by well sorted sediment, but several stations showing a mixture of mud with sand near Kunsan (5.5%) were found.

Sediment fauna

A total of 94 taxa have been collected. The polychaete involved the largest number of taxa (50 among 94 species) and then the pelecypod (16 species), crabs (12 species) and gastropod (7 species). Two of holothurian species were found: one of which *Protankyra bidentata* was considered for typical of the outer tidal flat. The living fossil species belonging to the brachiopod, *Lingula anatina*, was found overall on the coast, but mostly near Kimje, especially in the middle intertidal in so far as the sediment was a mixed type of silt with mud.

Data on density (individual numbers per m^2) and frequency (% occurrence at sampling stations) of the most abundant 19 taxa on 8 tidal flats are presented in Table 1. The taxa listed in Table 1 belonged mostly to infauna. Occurrence of epifauna would be poorly described by samplings with a box core covering an area of 0.02 m^2 employed in this study.

The most dominant species listed in Table 1 would, therefore, give a different perception from that obtained when we observe the tidal flat at a glance. For example, the gastropods such as *Bullacta exarata* and *Hinia festiva* were frequently found with naked eye on the silty sediments, however, those taxa ranked second dominant group in Table 1. In spite of those shortages, we could define characteristic species at different localities and sediment faces. Followings describe the characteristic species of each tidal flat from north to south.

Table 1. Densities (number of individuals per m^2) and % occurrence (frequency) in percent of number of stations occurred among total stations (n) investigated) of dominant species on the Korean tidal flat. Frequencies are indicated in the parenthesis. The species are sorted by the similarity of occurrence and listed by that order. Abbreviations are as P: polychaetes, G: gastropods, Br: brachiopods, H: holothurians, B: bivalves, D: decapoda.

Taxon	Songdo	Young-jongdo	Panweol	Hwa-sung	Daesan	Kun-san	Kimje	Buan
	(n=23)	(n=16)	(n=22)	(n=16)	(n=23)	(n=17)	(n=31)	(n=19)
Heteromastus sp. (P)	+	5 (56)			55235 (100)	3 (41)	2 (10)	4 (41)
Umbonium thomasi (B)	7 (13)			33 (63)	8375 (13)	2 (24)	27 (55)	929 (82)
Lingula anatina (Br)	115 (70)				100 (9)	45 (71)	34 (81)	20 (88)
Protankyra bidentata (H)	13 (48)					4 (18)	3 (35)	
Mactra veneriformis (B)							14 (48)	+
Lumbrineris nipponica (P)					950 (39)			
Nepthys polybranchia (P)					1425 (35)			
Laternula cf. *limicola* (B)						3256	130 (6)	10 (12)
Potamocorbula amurensis (B)			1006 (18)			(24)		
Sinonovacula constricta (B)		+	+	59 (13)				
Magelona japonica (P)		245 (44)		8 (19)	25 (4)			
Ilyoplax dentimerosa (D)		2 (6)	66 (59)	11 (69)				
Nephtys californiensis (P)		50 (88)						
Nitidotellina minuta (B)		221 (63)						
Perinereis aibuhitensis (P)		3 (6)	8 (68)	16 (56)			2 (16)	17 (18)
Ilyoplax pingi (D)		7 (25)	22 (45)	26 (69)		2 (12)		2 (24)
Mediomastus sp. (P)		9 (50)		13 (56)	1075 (43)	6 (41)		
Bullacta exarata (G)	27 (5)	36 (81)	+		225 (13)		6 (55)	4 (29)
Hinia festiva (G)	22 (39)	7 (56)	+			5 (41)	6 (29)	13 (65)

The most dominant species on the Songdo tidal flat was the holothurian species *Protankyra bidentata* which occurred largely in sandy sediments. Eleven species are listed as characteristic of the Panweol tidal flat, among them the pelecypod, *Potamocorbula amurensis,* ranked the first dominant. However, the Panweol tidal flat is an area located in the inner-most area of a tidal inlet and the burrows and the sediment mounds of crabs constituted the conspicuous surface structures of the tidal flat. Crabs such as *Helice tridens sheni* and *Macrophthalmus japonicus* were typical of the mud flat zone. The small crabs, *Ilyoplax dentimerosa* and *I. pingi*, whose carapace length is less than 1 cm were dominant in terms of abundance, but most crabs wandering around and to be seen because of the active behavior were the larger-sized crabs as *H. tridens sheni* and *M. japonicus*. The bivalve *P. amurensis* was mostly found in the channel sediment and, therefore, not conspicuous to the observer. The occurrence of the large-sized polychaete, *Periserrula leucophryna,* could be reported. The largest specimen was 56 cm in length and 1.3 cm in width. The bell-shaped sediment mounds on the middle intertidal belonged to this polychaete.

Fauna on the Hwasung tidal flat located about 10 km to the south of Panweol was characterized by the dominance of bivalve *Sinonovacula constricta* which has long been used for human food in Korea. The predominance of crabs was similar to the Panweol tidal flat. The polychaete *Perinereis aibuhitensis* which ranked the fifth in abundance is a worm used for bait by angler. Catches have been exported to Japan.

The Daesan tidal flat was represented by diverse fauna due to the diverse sediment types. This tidal flat was an area of strongest current flow. Heterogeneous mixture of mostly poorly sorted sediments were found. Large ripples, gullies and channel were well developed. Predominant current flow is from Asan Bay into Garolim Bay, which is reflected in the derivation of many of the tidal flat organisms. The predominance of the polychaete, *Heteromastus* sp. which was mostly found in fine sediments around Korean waters, was unique for the silty to sandy faces near the channel of the Daesan tidal flat. The gastropod *Umbonium thomasi* was typical of the outer flat.

The Kunsan, Kimje and Buan tidal flat produced the largest number of species in unique combination for this habitat (Table 2). The highest occurrence of the bivalve *Laternula* cf.

Table 2. List of species occurred on Kunsan, Kimje and Buan tidal flats. Individual numbers presented in the table are total counts from 69 stations investigated. +: occurred but not counted.

Species name	No. of indiv.	Freq. (%)	Species name	No. of indiv.	Freq. (%)
CNIDARIA			*Uca arcuata*	5	4.3
Pennatulacea indet.	201	15.9	Amphipoda indet.	+	
MOLLUSCA			Anomura indet.	15	4.3
Batillaria multiformis	150	4.3	ECHINODERMATA		
Bullacta exarata	335	43.5	*Paracudina chilensis*	3	4.3
Coelomactra antiguata	16	13.0	*Protankyra bidentata*	150	21.7
Cyclina sinensis	17	13.0	Holothuroidea indet.	8	4.3
Dosinorbis japonicus	30	23.2	Ophiuroidea indet.	+	
Hinia festiva	444	31.9	POLYCHAETA		
Laternula cf. *limicoloa*	59563	13.0	*Amphictene japonica*	11	5.8
Mactra chinensis	110	4.3	*Arabella semimaculata*	9	7.2
Mactra veneriformis	464	30.4	*Diopatra sugokai*	7	8.7
Meretrix lusoria	14	13.0	*Glycera chirori*	+	
Moerella iridescens	101	15.9	*Glycera subaenea*	33	27.5
Neverita didyma	22	23.2	*Glycera* sp.	32	26.1
Potamacorbula amurensis	6	5.8	*Glycinde* sp.	11	11.6
Ruditapes philippinarum	115	15.9	*Haploscoloplos elongatus*	93	39.1
Scapharaca subcrenata	3	4.3	*Lumbrineris* sp.	53	30.4
Sinonovacula constricta	+		*Neanthes japonica*	117	14.5
Solen strictus	85	31.9	*Nectoneanthes latipoda*	10	7.2
Umbonium thomasi	18526	52.2	*Nectoneanthes oxypoda*	17	8.7
BRACHIOPODA			*Nephtys caeca*	+	
Lingula anatina	2198	76.8	*Nephtys ciliata*	+	
CRUSTACEA			*Nephtys oligobranchia*	12	2.9
Calinasa sp.	9	7.2	*Nephtys* sp.	128	58.0
Helice tridens sheni	12	8.7	*Owenia fusiformis*	28	8.7
Hemigrapsus penicillatus	2	4.3	*Perinereis aibuhitensis*	369	17.4
Ilyoplax pingi	166	26.1	*Periserrula leucophryna*	106	21.7
Ilyoplax dentimerosa	27	8.7	*Scolelepis* sp.	4	2.9
Macrophthalmus japonicus	100	30.4	*Marphysa sanguinea*	10	1.4
Macrophthalmus dilatatus	22	11.6	Capitellidae indet.	309	47.8
Orithyia sinica	+		Nereidae indet.	17	8.7
Philyra pisum	10	10.1	Phyllodocidae indet.	1	2.9
Scopimera globosa	77	30.4	Polynoidea indet.	1	2.9
Sesarma plicatum	+		Sigalionidae indet.	10	5.8
			sum	84556	100.0

limicola on the Kunsan tidal flat was due to the center of abundance near the channel connected to the Mangyung River. This taxon ranked also the first in abundance on the Kimje tidal flat, but the distribution was limited to stations located on the slope edge of the channel leading into the Dongjin River. The occurrence of a lingulid brachiopod *Lingula anatina* which has ranked the second in abundance on the Kunsan, Kimje and Buan tidal flat was found as a living species on the world coasts. The predominance of *Umbonium thomasi* in sandy to silty bottom was observed as shown on the Daesan tidal flat. The bivalve *Mactra veneriformis* which has ranked the fourth on the Kimje tidal flat is a representative species for cultivation on the Korean tidal flat.

Comparisons have been made between faunal composition and sediment faces. Assigning the dominant taxa at 167 stations into sediment faces from sand to silt and clay, we could define typical taxa of every sediment type. Typical animals are slight different at a specific locality, but an general trend can be described as in Table 3.

Table 3. Typical dominant species assigned to different sediment types. Percent in parenthesis is the ratio of the number of stations showing the sediment type among 167 stations.

Sediment type	Dominant species	Sediment type	Dominant species
Sand	*Protankyra bidentata*	Sandy silt	*Bullacta exarata*
(15.8%)	*Laternula* cf. *limicola*	(24.2%)	*Hinia festiva*
	Lingula anatina		*Sinonovacula constricta*
Silty sand	*Ruditapes philippinarum*		*Nitidotellina minuta*
(23.6%)	*Umbonium thomasi*	Silt (23.6%)	*Ilyoplax pingi*
	Lumbrineris nipponica		*Perinereis aibuhitensis*
	Lingula anatina	Mud (7.3%)	*Ilyoplax dentimerosa*
	Mactra veneriformis		*Macrophthalmus japonica*
Muddy sand	*Lingula anatina*		*Macrophthalmus dilatatus*
(5.5%)			*Helice tridens sheni*

The sand faces were characterized by *Umbonium thomasi* accompanied with *Protankyra bidentata.* The brachiopod *Lingula anatina* extended its distribution into the silty sand and muddy sand flat. The bivalve *Mactra veneriformis* was considered as typical of muddy sand faces, however it also occurred broadly on silty sand flat. Sandy silt sediment was populated by the epifauna *Bullacta exarata,* but the polychaete *Nephtys polybranchia* was comparatively rich in the sandy silt sediment without any preference of the locality. The razor clam *Sinonovacula constricta* was mostly present on the Hwasung tidal flat. *Nitidotellina minuta* counted as typical bivalve of silty sediment, but this species was confined to the Yeongjongdo tidal flat. Mud faces were found at 7.3% among 167 stations, however, the fauna was rich and diverse: Crabs as *Helice* and *Macrophthalmus* were conspicuous over the whole Korean tidal flat. The small crab *Ilyoplax dentimerosa* is listed as typical, because of the highest counts in core samples.

A general pattern of zonation could be described: Crabs *Helice* and *Macrophthalmus,* the gastropod *Bullacta exarata,* the brachiopod *Lingula anatina,* the clam *Mactra veneriformis* and the gastropod *Umbonium thomasi* occurred from higher to lower intertidal.

Secondary production of bivalves: *Mactra, Ruditapes* and *Sinonovacula*

Table 4 summarizes the annual production of clams estimated by Ricker's model based on data collected from the field observations at different localities. The production described in Table 3 is the net production in which the fisheries catches and losses by death are excluded. The highest production was shown by the razor clam *Sinonovacula constricta* and the lowest by surf clam *Mactra veneriformis*, but the latter showed the highest P/B ratio. The mean biomass of *M. veneriformis* was 629 g TWW m^{-2} and this estimate comprised to the weight of about 200 individuals. The individual weight of 3 g was then resulted. This size of individuals are less than two years old. The highest biomass of 2,678 g TWW m^{-2} was recorded by the razor clam *S. constricta.* The mean individual weight of 20 g, which weighed seven times of *M. veneriformis*, could also be estimated from the mean density data recorded as 130 g TWW m^{-2} on the Hwasung tidal flat.

Table 4. Mean density (indiv.m^{-2}), biomass (g DW m^{-2}) and annual production (g DW m^{-2}yr^{-1}) of edible bivalves on the Korean tidal flat. In the parenthesis are the total wet weight (g TWW) including shells.

Species name	Mean density	Biomass	Annual production	P/B Ratio	Locality
Mactra veneriformis	205	31.5 (629)	68 (1358)	2.15	Incheon-Songdo
Ruditapes philippinarum	292	62.0 (1221)	83 (1635)	1.34	Daesan
Sinonovacula constricta	130	134 (2678)	150 (2998)	1.12	Hwasung
Benthic microalgae			50 gC m^{-2} yr^{-2}		Incheon-Songdo

Commercial Catches

The commercially important fisheries catches around the Korean coast are drawn from four groups: shell fishes, crustaceans, echinoderms and macroalgae. Of these groups, the various shell fishes constitute by far the greatest tonnage (Table 5). The oysters, short necked clams (Manila clam), mussels and cockle shells account for the largest tonnages of catches. Of the mollusks, surf clams, razor clams and Venus clams have caught mostly on the west coast. All those are bivalves caught from the tidal flat, beside the pen shell inhabiting the sand bottom of the subtidal area in the west.

Table 5. Important commercial catches (metric tons per year) on the Korean tidal flat (1997).

Species name	Common name	Fisheries catches (ton yr^{-1})
Acetes japonicus	Shrimp	10193
Ruditapes philippinarum	Manila clam	7198
Tegillarca granosa	Cockle shell	2744
Mactra veneriformis	Surf clam	933
Meretrix lusoria	Hard clam	496
Sinonovacula constricta	Razor clam	206
Cyclina sinensis	Venus clam	113

In recent years, there have been abundant examples of the decline of fisheries catches of all types around Korean coast. Some of these declines are exemplified by landings of bivalves on the west coast. Until 1986, the annual catch of the surf clam *M. veneriformis* was about seven thousands metric tons, however, it declined to about one thousand metric tons after 1986. The yield which we had reached before 10 years has not recovered till today. *Ruditapes philippinarum* was the clam of which the annual catch was seven-folds higher than that of *M. veneriformis,* however, the catch at present is only about 60 thousands metric tons per year. The total catch of the Venus clam *Cyclina sinensis* is much lower than the above two bivalves species, but the decline in the catch is clearly shown. The hard clam *Meretrix lusoria* was known to be the best tasted bivalve in Korea and large portion of the landings had been exported to Japan. The annual yield in 1997 is only about 500 metric tons. *Meretrix lusoria* was a typical clam for sand bottom on the Incheon-Songdo and Kimje tidal flat in the west. The only catch which are not declined is the razor clam *Sinonovacula constricta,* but the occurrence is restricted rather to the mud flat, and therefore the annual catch is only in small amount.

Although not depicted in a Figure, commercial catches in the Kyeonggi Bay which possesses the broadest tidal flat in the west showed a sharp decline in the catch of *M. veneriformis* from 1988. Monthly catch of about 60 metric tons recorded in the Kyeonggi Bay comprised to about 80% of the total catch from the Korean coast. *R. philippinarum* was caught around 800 metric tons per month in 1987, but decreased sharply after 1988. The decline in the catch of *Cyclina sinensis* is also clear, however, the yield was down from 1990. The recent landings of *M. lusoria* is extremely small compared with those recorded in the beginning of 1980's.

Land earning from the Korean tidal flats during 20th century

A short historic review of the land earning from the Korean tidal flat given in Table 6 indicates that a significant portion of the tidal flat is reclaimed in recent years. But those alterations have begun in the 1920's during the period of Japanese occupation. Rice production was the main purpose. The area of salt marshes had been considerably modified at that time. Statistics in 1987 reported that the areal extent of the tidal flat as about 2,800 km^2, but the total tidal flat area must be summed with 405 km^2 which was dammed before 1945. If we add the area of 500 km^2 reclaimed during 1946-87, then the total dimension of the Korean tidal flat was about 3,700 km^2.

Table 6. Historic review of the land earning from Korean tidal flat from 1917 to 1998.

Length of the coast line, west sea, Korea (South)			3341 km		
Areal dimension of tidal flats in 1987			2815 km^2		
Area of land earned from the tidal flat in the recent history (km^2)					
1917 - 38	405.4	1946 - 60	6.3	1961 - 69	172.2
1970 - 79	193.7	1980 - 89	93.1	1990 - 94	98.5
1995 - continuing	764.0				
	405.	total area including the continuing			1733.2

The largest land earning is in the progress on the Kimje tidal flat. The government agency of Rural Development Cooperation (RDC) has launched the so called 'Saemankeum' project in 1991 with an expectation of accomplishing the project in 2004 (RDC, 1994). The 33 km long sea wall is constructing. The land which will be earned from this project is amounted to about 400 km^2. The lake produced after cutting the tidal flat covers an area of 120 km^2.

DISCUSSION

The mass land earning on the Korean coast in recent years was remarkable, however, the values of Korean tidal flats have not been assessed in an ecological and environmental view point. Primary and secondary productions recorded in the study areas rival those of Wadden Sea area. The reclamation projects have frequently been supported by the Ministry of Agriculture, Korea, with emphasis on an earning of rice field. The annual income of fishermen by catching the bivalve, *Mactro veneriformis,* amounted to about 0.8 million US$ per km^2. In the case of the razor clam, *Sinonovacula constricta,* the annual income has been reached to about 2 million US$ per km^2 because of the higher market price. Although the economic importance of fisheries has generally been declined on the Korean coast, the tidal flat sustains the capacity of fisheries catches and possibilities in economic uses are still remained.

The levels of pollutants in the Korean coastal waters have been increased in recent years and a reason for that was supposed to be related with those embankments of tidal flat area (MEK, 1995; Koh, 1996). A concrete example can be shown from the saline lake Sihwa which was isolated from the sea by a dike construction in 1994. A sharp increase in concentrations of heavy metals and organic materials in lake sediments are reported (Lee and Koh, 1998). The bottom fauna was changed to the polychaete, *Polydora ligni,* which was known to be tolerant to higher concentration of organic matters in sediments with high sulfide. Even an azoic zone of several square kilometers was found. The reason of the higher concentration of pollutants and its bioeffects in the lake was the locality of the enclosure. The dike closed the seawater which received discharges from the industrial complex and the city of Ansan populated by more than 0.3 million people.

We are collecting data on ecology, fisheries, and social economy concerning the Korean tidal flat. It was clear, however, that the Korean tidal flat has been deteriorated through the land earning without less assessment of environmental impacts. Comparing the coastal uses in Korea with developed countries as German on the North Sea coast, it can be indicated that the Korean government policy on the conservation is still in primitive stage.

The coastal countries of Wadden Sea have established the concept of wise use and sustainable development enforcing a better conservation strategy to manage the Wadden Sea ecosystem (CWSS, 1990). Three countries including German have decided to develop a common approach which can be characterized by a complex strategy. Assessments of the quality of tidal flat ecosystem have been performed (NNW, 1994, NSHW, 1994).

Study on the tidal flat ecosystem in Schleswig-Holstein includes various aspect of ecology in tidal flat (NSHW, 1994): The study involved plankton, benthos with emphasis on crabs, bivalves and their fisheries, waterfowl, and wild life, especially the seals. Chemical data on heavy metals and organic compounds have also been produced. The relationship between the human and tidal flat ecosystem was also an important aspect raised by this report. All the information was displayed with GIS system and, therefore, informative to the public.

The situation in Korea should better be improved as far as it concerns with conservation strategies of tidal flats. Even an assessment of tidal flat ecosystem have little been attempted. Many works are needed to develop a program for conservation and wise use. A more important aspect is, however, that the ecological assessment should be included in planning of land uses and inevitable setting of industrial complexes. Still yet, policy makers tend to establish projects of tidal flat reclamation rather in developmental aspects, not in ecological.

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ANALYZING IMPLEMENTATION OF THE HAWAII OCEAN RESOURCES MANAGEMENT PLAN

Craig D. MacDonald and J. Claire Cappelle

State of Hawaii Department of Business, Economic Development and Tourism
Honolulu, Hawaii, U.S.A.
cmacdona@dbedt.hawaii.gov

ABSTRACT

The *Hawaii Ocean Resources Management Plan* (ORMP) is the guiding document for the State to achieve comprehensive and integrated ocean and coastal resources management. A total of 66 policies and 364 actions in ten resources sectors are formulated for implementation by 16 designated federal, state and county agencies and are the focus of this analysis. The ORMP was published and implementation began in 1991, but the status of its implementation has not previously been systematically assessed. The following findings are based on a survey of the designated agencies, conducted over the period May 1996 - March 1997.

- A basic inconsistency between the priority and status of recommended actions (e.g. high priority, low status) was indicated for the sectors on research and education, ocean recreation, marine ecosystem protection, beaches and coastal erosion, and harbors.

- The fisheries and energy sectors are distinguished by the relatively large number of actions that were ranked low in priority and not considered.

- Good agreement between the priority and status of recommended actions was expressed for the sectors on waste management, marine minerals, and aquaculture.

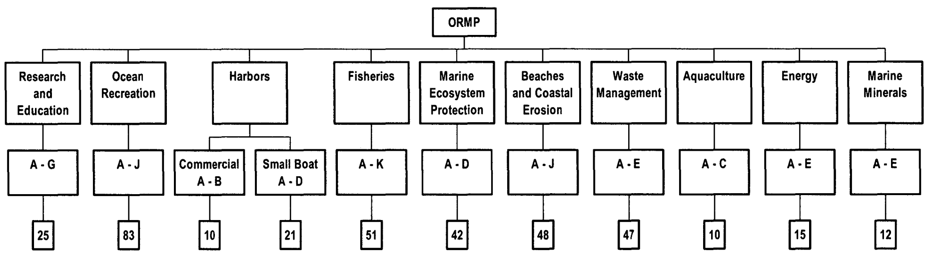
- In numerous recommendations that multiple agencies work cooperatively to implement an action, a condition evident in five of the ten sectors (ocean recreation, harbors, marine ecosystem protection, beaches and coastal erosion, and energy), omission of a specified lead agency has resulted in the lack of concerted effort.

- A multi-agency body with public representation and legislative oversight is needed to serve as the forum to address these findings and coordinate more effective implementation of the ORMP, especially for actions requiring multiple agency cooperation.

INTRODUCTION

The *Hawaii Ocean Resources Management Plan* (ORMP), published in 1991, was mandated by state statute (Chapter 228, Hawaii Revised Statutes [HRS], enacted 1988) and developed by a multi-agency, cabinet-level council which included private sector and non-governmental representatives. The ORMP sets forth guiding principles and recommendations for the State of Hawaii to achieve comprehensive and integrated ocean and coastal resources management (Hawaii Ocean and Marine Resources Council, 1991). The ORMP resulted from the need to improve multi-jurisdictional management of the second largest marine area in the U. S. (i.e., Hawaii's territorial sea and adjacent Exclusive Economic Zone) and to maintain the viability of ocean industries that grew rapidly from $1.3 billion in gross revenues in 1981 to $2.9 billion in 1992 (MacDonald, 1995; MacDonald and Deese, 1995).

In addition to overall recommendations for a new governance structure and a comprehensive management system, the plan includes a series of specific policies and implementing actions for ten resource sectors. Reflecting the comprehensiveness of the plan, 66 policies and 364 associated implementing actions are recommended (Figure 1). These policies and actions are formulated for implementation by 16 designated federal, state and county agencies, often in coordination with research institutions, non-governmental organizations and private interests, and are the focus of this analysis.



Level One - Ocean Resources Management Plan (ORMP)
Level Two = Resource Sectors [n = 10]
Level Three = Policies [n = 66]
Level Four = Actions [n = 364]

Figure 1. Organizational components of the *Hawaii Ocean Resources Management Plan.*

Implementation of ORMP policies and actions began in 1991, upon publication of the plan and its submittal to the Hawaii State Legislature. The plan was formally adopted by the State Legislature in 1994 (House Concurrent Resolution No. 246, Senate Draft 1; House Concurrent Resolution No. 228), following several years of legislative debate on ORMP recommendations for a new governance structure. Legislation subsequently was passed in 1995 (Act 104, State Laws of Hawaii) that amended the State coastal zone management law (Chapter 205A, HRS) and incorporated the plan into the Office of State Planning (now the Office of Planning) and its Coastal Zone Management (CZM) Program. The same legislation established the Marine and Coastal Zone Management Advisory Group (MACZMAG) to provide guidance and make recommendations for implementation of the ORMP. This legislative history and plan highlights are summarized in MacDonald and Clark (1995).

As the specified lead agency, the Office of Planning in the Department of Business, Economic Development and Tourism is providing oversight and coordination for implementation of the ORMP. However, the comprehensive, far-reaching nature of the plan, combined with recent fiscal restraints on State government agencies, has led to difficulties in adequately monitoring and assessing the status of plan implementation. To meet the need for updated information and evaluation, a mail-out survey of all agencies designated in the plan was undertaken and a quantitative analysis of the responses was conducted.

This paper summarizes, for the first time, the priority and status of the sector-specific recommendations as indicated by the designated agencies. The assessment is limited to analyzing the relationship between what the ORMP recommends, the importance attached to the policies and actions by the agencies, and what is being done to further the plan's implementation. The analysis does not determine the extent or effectiveness of ORMP implementation, nor does it measure program output per se; it is not a performance audit.

METHODS

Survey

On behalf of the MACZMAG, surveys to determine the priority and status of the sector-specific policies and implementing actions in the ORMP were sent to the directors and program heads of all agencies designated in the plan (Table 1). A sample survey questionnaire is included as an Appendix. The terms "priority" and "status" are defined categorically in the Analysis section below. The survey was conducted over the period May 1996 - March 1997, and included follow-up phone interviews and selected presentations to the MACZMAG by participating agencies. Agencies were asked to respond only to the policies and actions which they were designated to implement.

The surveys covered the ten resource sectors in the ORMP: research and education, ocean recreation, harbors, fisheries, marine ecosystem protection, beaches and coastal erosion, waste management, aquaculture, energy, and marine minerals. All of the agencies queried in the survey returned completed survey forms. In summary, of the total 364 implementing actions stipulated (including all subsets), only two have been completed; for two more, the responsible program was abolished and for two others, the program was not established. Only five of the recommended actions received no response, absent any explanation.

Analysis

In this paper, the sector response rate is defined as the percent of actions responded to in the survey by at least one of the agencies so designated. This measure has a tendency to overestimate the true response rate in cases where multiple agencies are designated for a single action, but not all agencies respond. Examination of the individual survey responses in such cases reveals that this is not a serious source of bias, given the degree of data aggregation involved and the overview perspective intended.

Table 1. Summary of government agencies designated in the *Hawaii Ocean Resources Management Plan* and surveyed as the basis for this analysis. Acronyms in parentheses are mentioned in the Results section of the text.

Federal Agencies
U.S. Army Corps of Engineers, Honolulu District
U.S. Coast Guard, Fourteenth District
U.S. Department of Commerce
  National Marine Fisheries Service, Pacific Area Office - Southwest Region
  Western Pacific Regional Fishery Management Council

State Agencies
Department of Budget and Finance
Department of Business, Economic Development, and Tourism (DBEDT)
Department of Education
Department of Health (DOH)
Department of Land and Natural Resources (DLNR)
Department of Transportation
Office of State Planning (OSP) [currently Office of Planning in DBEDT]
University of Hawaii

County Agencies
City and County of Honolulu, Department of Land Utilization
County of Hawaii, Department of Planning
County of Kauai, Department of Planning
County of Maui, Department of Planning

An index of coherence was developed to assess the strength of agreement between the priorities (*high, medium, low*) attached to a sector's implementing actions and the status of the actions (*ongoing, planned/budgeted, planned/not-budgeted, not considered*). The index is a collective measure and a general way to characterize the relationship between priorities and the status of recommended actions for a sector. It is used as a diagnostic tool for screening sectors and identifying those that need further evaluation.

The index is calculated for each sector by expressing the combined *high and medium* priority rankings as a percentage of the total, and dividing by the percentage of the actions tallied as *not considered* (i.e. given lowest status). These percentages and their corresponding indices are shown in bold in Table 2. This calculation produces an index that generally increases with the strength of coherence (agreement) between priority and status; exceptions are noted in the text. Discrepancies occur when high and medium priority recommendations are not supported by programs or funding (i.e. not considered).

Table 2. Aggregate responses given for priority rankings (n = 681) and status of action (n = 653) indicated in the *Hawaii Ocean Resources Management Plan* survey. Percents are used to calculate the index of coherence for each sector as explained in the "Methods" section of the text.

	PRIORITY					STATUS					INDEX
Resource Sector		High	Med		Low	Ongoing	Planned/ Budgeted	Planned/ Not Bud	Not Considered		
Research & Education	**63%**	6	11	17	10	8	0	5	14	**52%**	**1**
Ocean Recreation	**84%**	103	92	195	37	84	6	64	79	**34%**	**2**
Harbors	**74%**	28	14	42	15	20	1	19	15	**27%**	**3**
Fisheries	**51%**	26	5	31	30	22	0	3	34	**58%**	**1**
Marine Ecosystem Protection	**77%**	30	25	55	16	30	0	11	29	**41%**	**2**
Beaches & Coastal Erosion	**74%**	60	40	100	36	28	6	42	35	**32%**	**2**
Waste Management	**96%**	27	16	43	2	35	0	7	3	**7%**	**>10**
Aquaculture	**92%**	8	4	12	1	9	0	4	0	**0%**	**>10**[a]
Energy	**52%**	5	7	12	11	6	1	3	13	**57%**	**1**
Marine Minerals	**88%**	12	2	14	2	11	1	4	1	**6%**	**>10**

[a] Calculation of the coherence index with zero in the denominator (92/0) was solved by adding 1 to each term.

RESULTS

The ORMP survey results are summarized and the indices of coherence for the various resource sectors are presented in Table 2. Figure 2 illustrates the frequency distribution of the coherence indices for the ten resource sectors. The agency response rate was consistently high, 100% for all but three sectors: ocean recreation (98%), waste management (96%) and marine ecosystem protection (93%). The results depicted in Table 2 and Figure 2 are analyzed and briefly discussed by sector.

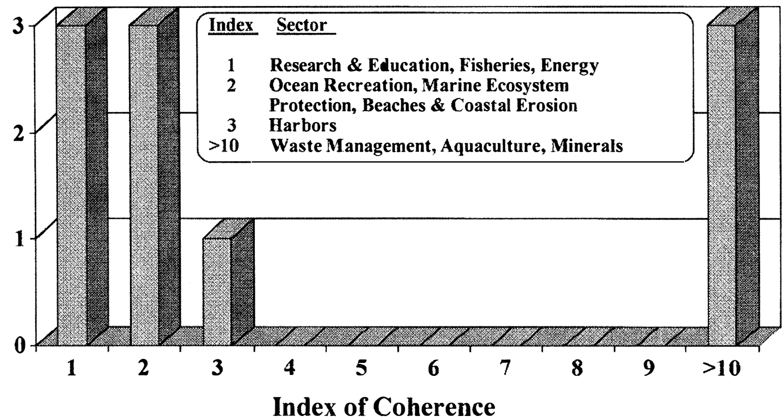


Figure 2. Frequency distribution of coherence indices for the ten resource sectors in the *Hawaii Ocean Resources Mangement Plan.* Indices are keyed to resource sectors in the insert.

Acronyms in parentheses in the text indicate state agencies designated to implement policies, wherein discrepancies occurred (refer to Table 1 for details). There was no lead agency designated in the following cases, where multiple agency coordination was required and discrepancies occurred.

Research and Education: Priority rankings were moderately high-medium (63% of responses). In terms of status, about half of the actions (52%) were not considered. The coherence index was low ("1"). The greatest discrepancies were in policies involving mitigation of user conflicts, definition of "marine education" to prevent unintended activities and provision of expanded interpretive education (DLNR).

Ocean Recreation: Priority rankings were predominantly high-medium (84% of responses). In terms of status, slightly more than a third of the actions (34%) were not considered. The coherence index was relatively low ("2"). Discrepancies mostly occurred in policies designating actions that are to be undertaken cooperatively by **multiple** state and county agencies; they involve provision of recreational facilities, development of water safety programs and means to limit use.

Harbors: Priority rankings were predominantly high-medium (74% of responses). In terms of status, only slightly more than a quarter of the actions (27%) were not considered. The coherence index was relatively low ("3"). Discrepancies involved the same policy action (i.e., water quality and marine life monitoring) designated for both commercial and small boat harbors and requiring **multiple** agency cooperation.

Fisheries: Priority rankings of high-medium made up about half (51%) of the responses. In terms of status, somewhat more than half of the actions (58%) were not considered. Notably, despite the low coherence index ("1"), there was generally good agreement between priority and status of action. This is due to the relatively large number of actions that were ranked low and not considered. Discrepancies occurred in policies involving development of a management plan for inshore/nearshore fisheries, clarification of native Hawaiian fishing rights and reevaluation of existing fishing regulations (DLNR).

Marine Ecosystem Protection: Priority rankings were predominantly high-medium (77% of responses). In terms of status, slightly less than half of the actions (41%) were not considered. The coherence index was relatively low ("2"). Discrepancies mostly occurred in a single policy. This policy designates actions that are to be taken cooperatively by **multiple** federal, state and county agencies to facilitate coordinated and comprehensive interagency management where jurisdictional overlaps exist.

Beaches and Coastal Erosion: Priority rankings were predominantly high-medium (74% of responses). In terms of status, only about a third of the actions (32%) were not considered. The coherence index was relatively low ("2"). Discrepancies occurred in most of the policies and are too numerous to list here. Except for one policy in which OSP was designated, these policies stipulate actions that are to be taken cooperatively by **multiple** state and county agencies.

Waste Management: Priority rankings were heavily high-medium (96% of responses). In terms of status, only a small percentage of the actions (7%) were not considered. The coherence index was high (">10"). Discrepancies were few and occurred in a single policy, which involved ensuring for the adequacy of sewage treatment facilities to prevent discharge of untreated sewage into nearshore waters (OSP) and ensuring that hazardous waste incineration was fully monitored with the results being readily available to the public (DOH).

Aquaculture: Priority rankings were heavily high-medium (92% of responses). In terms of status, no actions were not considered (i.e., all actions were ongoing or planned). The coherence index was high (">10"). Calculation of the index, with zero in the denominator (92/0), was solved by adding one to each term. The majority of policies involved only a single agency (DLNR). There were no discrepancies.

Energy: Priority rankings of high-medium made up about half (52%) of the responses. In terms of status, slightly more than half of the actions (57%) were not considered. The coherence index was low ("1"). Nonetheless, there was generally good agreement between priority and status of action. This is due to the relatively large number of actions ranked low and not considered. Discrepancies occurred in two policies, both of which stipulated actions requiring **multiple** agency cooperation. These policies involved inventorying ocean energy resources and determining their development impacts to marine environments, as well as coordinating and streamlining the permitting process for ocean energy activities.

Marine Minerals: Priority rankings were predominantly high-medium (88% of responses). In terms of status, most actions were ongoing or planned; only 6% were not considered. There was high coherence (index of ">10") and no discrepancies. If an action was ranked low, it usually was not considered.

One state agency, DLNR, is designated to implement actions in nine of the ten resource sectors (i.e. all but waste management). It is designated in 91% of all implementing actions involving multiple agencies and 58% of the total number of implementing actions overall. It accounted for 25% of the total responses to the action status category "not considered". This agency should be viewed as the linchpin for realizing fuller implementation of the ORMP.

CONCLUSIONS

In our analysis, a coherence index of "1" signifies that only half of the actions recommended in the ORMP are being implemented. That is essentially the case for the research and education, fisheries, and energy sectors. An index greater than "1" indicates that proportionately more of the actions are being implemented with increasing degree of priority assigned. That is evident in the other sectors.

Good coherence exists between the priority and status of recommended actions for the waste management, marine minerals, and aquaculture sectors. Reasonably good coherence also is evident in the fisheries and energy sectors despite the low index ("1") calculated for each. That anomaly is due to the relatively large number of actions that were ranked low in priority and not considered. Both of these sectors merit closer examination and fuller explanation of these circumstances[1].

The generally low coherence found between the priorities and status of the recommended actions for the other sectors (research and education, ocean recreation, marine ecosystem protection, beaches and coastal erosion, and harbors), indicates a basic inconsistency between the importance attached to much of what was recommended and what is being (or in this case not being) done. These latter sectors are the most in need of further attention to resolve the inconsistencies between priorities and status of recommended actions.

An obvious source of these inconsistencies is the frequent stipulation (occurring in 45% of all sector-specific recommendations) that multiple agencies work cooperatively to implement an action. In many cases, a lead agency is not specified, and there can be widely differing sets of responses to the question of priority and status. This condition is evident in five out of the ten resource sectors, and is a contributing cause of the low index values of "1 "and "2". The multi-agency MACZMAG, with public representation and legislative oversight mandated by statute, is ideally constituted to serve as the forum to reconcile these vagaries and, therein, to coordinate more effective implementation of the ORMP.

DISCUSSION

Further Considerations

When responding to the survey, agencies may have had some difficulty in linking actual projects and activities that are ongoing to the policies and implementing actions as they are expressed in the ORMP. This possibility derives from the hiatus between submittal of the ORMP to the Legislature in 1991 and its institutionalization in the CZM program in 1995. Bias of this sort would make our analysis conservative, since it tends to underestimate the full degree of ORMP implementation.

[1] During the survey period, DBEDT made a presentation on the energy sector to the MACZMAG explaining that, in the years following preparation of the ORMP, State energy policy changed in response to shifts in alternate energy markets, thereby lowering priorities and limiting implementation of the recommended actions. This situation was also the source of explanatory comments by DBEDT submitted with the completed survey form.

The results of this survey identified many of the policies and implementing actions as ongoing, without describing the associated projects or activities. Such descriptions were not critical to meeting the objective of the present evaluation, which is largely diagnostic. Lacking this information, however, it is difficult to assess mitigating factors impinging on policies and actions and to determine the success with which sector-specific recommendations have been implemented. To offset this limitation, the following steps are being taken by the CZM program under the auspices of the MACZMAG: (a) an ORMP assessment by an independent contractor, (b) a one or two day "summit," and (c) preparation of a summary legislative report.

The contractor assessment is completed and has gathered fuller information on ORMP-related program details and the extent of implementation, building on our analysis and moving to the next phase of evaluation (Lowry et al., 1998). The "summit" will provide an opportunity for the designated agencies to report on the actions they have taken and will encourage public dialogue and debate regarding the effectiveness of ORMP implementation. Recommendations in the report to the State Legislature could form the basis for new legislation to update the objectives and improve the efficiency of ORMP implementation.

Broader Context

The significance of the present paper extends beyond its relevance to Hawaii. To our knowledge, this is the first published account of a quantitative, summative evaluation of a comprehensive ocean management plan. Current texts on coastal zone management (Clark, 1996) and integrated coastal and ocean management (Cicin-Sain and Knecht, 1998) make little mention of evaluating policy plans for comprehensive ocean management, while being very thorough otherwise. This relative lack of attention probably is because very few such plans have been developed and adopted by the coastal states.

Besides Hawaii, Oregon is the only state to formally adopt and institute a comprehensive ocean management plan (Oregon Ocean Resources Management Task Force, 1991). California recently has developed such a plan and is in the process of furthering its institutionalization (Resources Agency of California, 1997). Other states, including Washington, North Carolina, Florida and Mississippi, have instead developed policy reports or established guidelines and mechanisms as antecedents to possible plan development (e.g. Christie, 1989; McLaughlin and Howorth, 1991).

The regional or site-specific level of ocean management planning is more prevalent, particularly in regard to marine habitat (Gordon, 1994). The regional action plan for the Gulf of Maine, adopted by five states and provinces in two countries, exemplifies a coordinated planning approach to the conservation of a large marine ecosystem (Gulf of Maine Council on the Marine Environment, 1991). Marine sanctuary management plans adopt an integrated ocean and coastal management approach, but also are regional in extent (e.g. Florida Keys National Marine Sanctuary, 1996; Hawaiian Islands Humpback Whale National Marine Sanctuary, 1997). A summary assessment of marine area management is provided by the National Research Council (1997).

ACKNOWLEDGMENTS

This paper updates and summarizes the findings of a report submitted to the Nineteenth Legislature of the State of Hawaii, Regular Session of 1998 (Office of Planning, 1998). That report was prepared by us, in coordination with the MACZMAG Subcommittee on ORMP Implementation (C. MacDonald, Chair) and with the assistance of Jeffrey S. Walters. Assistance in developing and pretesting the survey instrument was provided by Athline M. Clark, Richard G. Poirrier and Brian Burnett. This paper is Ocean Resources Branch Contribution No. 141.

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APPENDIX: Sample Survey Questionnaire (partial)

AQUACULTURE							
OBJECTIVE: Develop an integrated approach to manage the impacts associated with an expanded aquaculture industry in Hawaii, while maintaining the viability and integrity of the environment.				Comments, if any:			
Policy A: Assess the economic, social, and environmental costs and benefits of expansion in the various sectors of the aquaculture industry.				Comments, if any:			
Implementing Actions	**Priorities**			**Status**			
DLNR should:	**High**	**Medium**	**Low**	**Ongoing**	**Planned/ Budgeted**	**Planned/ Not Budgeted**	**Not Considered**
1 Identify the positive and negative impacts of expanding the various sectors of the aquaculture industry.							
2 Establish priorities for support of the various industry sectors.							
3 Create a coordinated development strategy to direct the industry along the path most beneficial to the economic, social, and environmental well-being of Hawaii.							
4 Consider the needs of the aquaculture industry for fresh water in relation to competing water uses.							

Policy B: Mitigate user conflicts between the aquaculture industry, fishermen, and the public at large.				Comments, if any:			
Implementing Actions	**Priorities**			**Status**			
DLNR should:	**High**	**Medium**	**Low**	**Ongoing**	**Planned/ Budgeted**	**Planned/ Not Budgeted**	**Not Considered**
1 Investigate alternative means to resolve disputes between these communities.							
2 Investigate the feasibility and desirability of expanding the Ocean Leasing Law to allow commercial aquaculture facilities in nearshore waters.							

CHARACTERISTICS OF ENVIRONMENT OF THE COASTAL ZONE IN A METROPOLITAN AREA OF TOKYO BAY

Takamasa Miyazaki[1] and Kiminori Nakazawa[2]

[1]College of Industrial Technology,
Nihon University
Narashino, Chiba, Japan
Miyazaki@arch.cit.nihon-u.ac.jp

[2]College of Industrial Technology, Nihon University
Narashino, Chiba, Japan
Kiminori@can.bekkoame.ne.jp

ABSTRACT

This research employs a multi-dimensional spatial and historical approach to identify and analyze past, current and emerging trends in land utilization patterns along the northern coast of the Tokyo Bay. The target area includes a strip of coastline several kilometers in width, and stretching from southern part of Yokohama to Kawasaki in the north. Quantitative data for nine variables, Regional Planning, Existing Land Use, Land Use Mixture, Population Density, Landfill History, Rail Access, Main road Access, Distance from Green Park and Distance from Waterline, were obtained and mapped on l00m X l00m grids. Correlations between the variables was undertaken.

The results show that many fundamental differences in land utilization and population structure between the older inland sections and the newer landfill areas near the coast. These differences are due to the practice of developing landfill areas as isolated islands, with little integration into their surroundings. Suggestions for improvements included increase in public access to the coast, more flexible, mix and complex restrictions on land use, and transportation systems which allow residents better access to open space and waterfront facilities.

INTRODUCTION

During the 1980s there was a strong movement to redevelop Japanese waterfront and riverside areas, with an emphasis on ease of access and multiple uses. The coastal industrial areas developments of the high growth years of the postwar period were to be improved with urban functions and amenities.

Unfortunately, with the downturn in the economy many of these plans have not been implemented. At this stage there is an urgent need to understand the rapidly changing land use patterns in the coastal zone, and to begin rethinking basic priorities.

Urban coastal zones are extremely complicated. They often contain vital port and transportation facilities, and in congested areas may provide the only opportunity for expansion and development. On the other hand, the coastal areas serve important ecological

Table 1. Existing Land Use

Area	Industrial	Commercial	Agriculture	Open Space	Public	Residence	Transportation	Transit	Green
Area 1	15"	8"	0%	7"	7"	53"	8"	2"	0%
Area2	63"	1"	0%	10%	3"	4"	5"	15"	0%
Area3	2"	5"	10%	12"	7"	48"	3"	4"	10"
Area4	33"	2"	0%	3"	9%	32"	7"	13"	0%
Area5	5"	4"	4"	7"	7"	61"	6"	3"	4"
Area6	2%	14"	0%	15%	13"	37"	13"	7"	1%
Area7	1"	2%	2%	12"	9"	61%	4%	1"	8%
Area8	6%	2%	1%	12%	9%	61"	2%	2%	6%
Area9	20%	2%	0%	9%	7%	30%	4%	27%	2%
Area10	8%	2%	2%	28%	8%	33%	2%	4%	13%
Overall	17%	3%	2%	13%	8%	40%	5%	8%	5%

From Figure 2.

4- **Regional Planning** Land use categories as designated in regional planning documents were utilized. The zoning categories identified were:

Category 1 exclusive low-rise residential (Residential 1)
Category 2 exclusive low-rise residential (Residential 2)
Category 1 exclusive mid-to-high-rise residential (Residential 3)
Category 2 exclusive mid-to-high-rise residential (Residential 4)
Category 1 exclusive residential (Residential 5)
Category 2 exclusive residential (Residential 6)
Light residential, Neighborhood commercial (N-Commercial)
Commercial, Light industrial
Industrial, Exclusive industrial use (E-Industrial)
Urbanization control area (U- control area), Others

5- **Landfill History** Year of landfill or pre-existing land.

6- **Main Road Access** Straight line distance to the nearest major road (not including toll roads).

7- **Rail Access** Distance to nearest train station.

8- **Distance from Waterline** Straight line distance from waterline.

9- **Distance from Green park** Straight line distance to nearest park or other public space.

PRIMARY RESULTS

The nine variables were researched and analyzed according to the 10 areas.

1- **Existing Land Use**
The following four patterns were identified:

Industrial Dominated Area 2
Industrial/Residential Mixed Areas 1,4, 9
Residential Dominated Areas 3,5,7, 8~ 10
Commercial Dominated Area 6 (central Yokohama)

2- **Land Use Mixture and Population Density**
The overall average of land use mixture was 1.322. Mixture was low in the Industrial Dominated areas, where land use is restricted, and high in the Commercial Dominated areas. Results of population density also shown in (Table 2). Almost two million people are living in the target region.

Table 2. Land Use Mixture and Population Density

Type	Area	Land Use Mixture	Population	Population Density(people/mesh)
Industrial Dominated	Area2	0.800	83,400	31.03
Industrial/Residential Mixed	Area1	1.599	155,275	139.89
	Area4	1.243	235,950	93.08
	Area9	1.158	101,100	65.23
	Average/Total	1.294	492,325	94.77
Residential Dominated	Area3	1.931	134,750	109.55
	Area5	1.476	154,675	126.06
	Area7	1.439	240,500	128.27
	Area8	1.284	451,125	116.09
	Area10	1.256	237,625	70.20
	Average/Total	1.390	1,218,675	105.03
Commercial Dominated	Area6	1.800	132,250	93.99
Overall	Average/Total	1.322	1,926,650	92.22

Table 3. Regional Planning

Type	Area	Residential 1	Residential 2	Residential 3	Residential 4	Residential 5	Residential 6	Light-Residentia	N-commercial
Industrial Dominated	Area2	0	0	0	0	0	35	1	17
Industrial /Residential Mixed	Area1	0	0	0	0	9	385	32	169
	Area4	83	0	0	206	171	180	66	157
	Area9	415	0	21	0	127	3	59	54
Residential Dominated	Area3	365	45	28	165	217	6	22	122
	Area5	446	0	204	287	383	22	16	242
	Area7	1,514	14	315	282	685	101	87	216
	Area8	1,072	0	164	107	322	53	68	78
	Area10	469	4	1	57	317	12	16	46
Commercial Dominated	Area6	194	0	45	25	150	11	2	129
Overall		4,558	63	778	1,129	2,381	773	368	1,213

Type	Area	Commercial	Light industrial	Industrial	E-industrial	U-control area	Others	Total
Industrial Dominated	Area2	367	84	135	1,950	0	93	2,682
Industrial /Residential Mixed	Area1	222	98	195	0	0	0	1,110
	Area4	372	236	92	944	0	28	2,535
	Area9	321	112	280	154	0	4	1,550
Residential Dominated	Area3	105	28	23	74	27	0	1,227
	Area5	163	40	4	0	68	0	1,875
	Area7	63	103	44	335	127	0	3,886
	Area8	11	77	501	67	853	18	3,391
	Area10	80	61	0	0	167	0	1,230
Commercial Dominated	Area6	691	15	128	11	0	6	1,407
Overall		2,028	770	1,267	1,585	1,242	56	20,893

Table 4 ; Additional Variables

Type	Area	Distance from Waterline (m)	Distance from Geen Park(m)	Landfill History	Main Road Access(m)	Rail Access(m)
Industrial Dominated	Area2	244	506	61	359	933
Industrial/Residential Mixed	Area1	688	420	150	199	625
	Area4	342	407	109	354	676
	Area9	435	345	86	382	897
	Average/Total	444	391	111	329	731
Residential Dominated	Area3	835	266	150	214	786
	Area5	836	285	146	214	440
	Area7	1,034	248	146	260	623
	Area8	925	261	132	331	722
	Area10	747	205	113	353	750
	Average/Total	871	246	132	301	691
Commercial Dominated	Area6	573	274	121	252	548
Overall	Average/Total	664	317	117	312	723

3-**Regional Planning**

Residential designations accounted for 48% of the total area, followed by industrial at 28% and commercial at 17%.

4- Landfill History, Main Road Access, Rail Access, Distance from Waterline and Distance from Green Park

Landfill history is expressed in number of years since landfill work was completed. As can be seen, the Industrial Dominant and Industrial/Residential Mixed areas tend to be closer to the waterline, while the Residential Dominant areas have best access to parks and public green zones. In terms of road and rail access, Commercial Dominated areas are closest, followed by Residential Dominated. Industrial Dominated areas scored lowest in rail and road access.

CORRELATED ANALYSES

In order to identify the interrelationships among the above variables, a series of secondary correlated analyses were implemented. A total of seventeen correlations were conducted.

1- Distance from Waterline

The distance from waterline was correlated against actual land use, population density, Rail access, road access, open space access and land use mixture.

As is clear, industrial use decreases, while residential use increases, as one moves inland. Population density follows a similar pattern, as do land use mixture and the access variables. From these results it is clear that the industrial areas near the coast lack residential facilities and urban amenities. Urban amenities such as rail and road appear to peak at a distance of about 7OO meters, and this distance can be seen as a sort of dividing line separating the monotonous coastal industrial areas from the more diverse areas further inland.

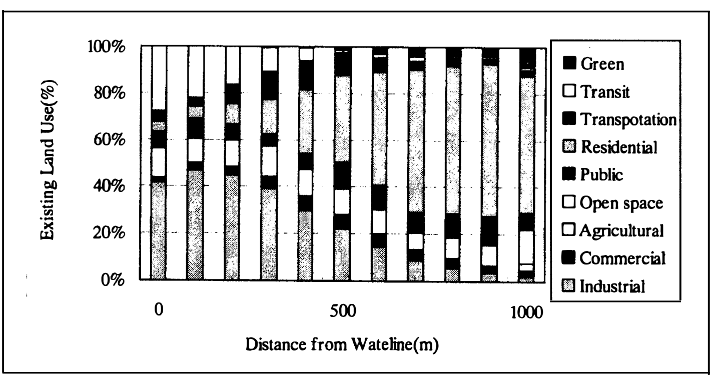

Figure 3. Distance from Waterline and Existing Land Use

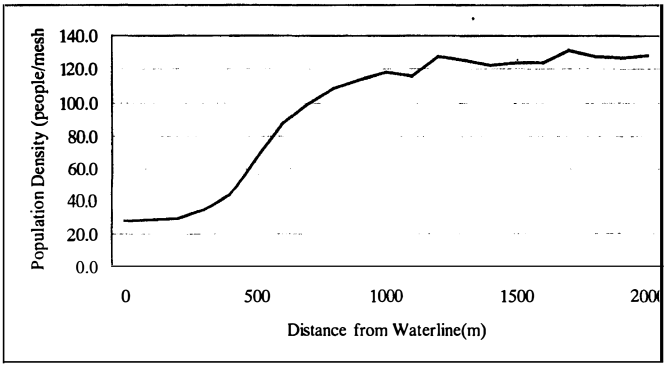

Figure 4. Distance from Waterline and Population Density

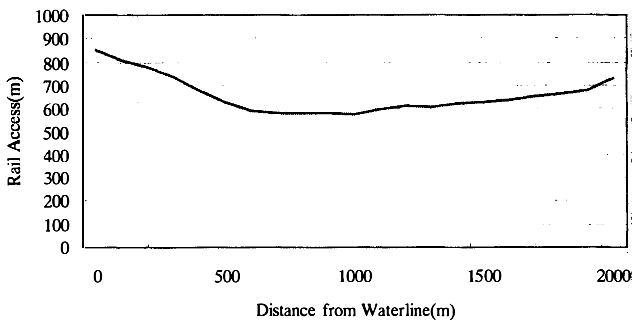

Figure 5. Distance from Waterline and Rail Access

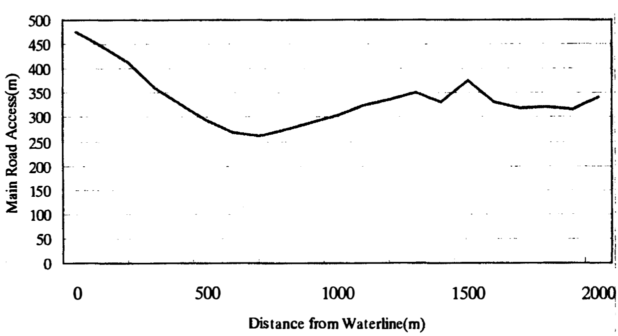

Figure 6. Distance from Waterline and Main Road Access

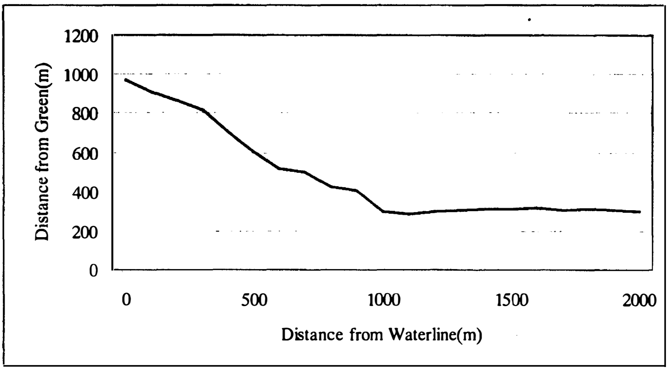

Figure 7. Distance from Waterline and Distance from Green Park

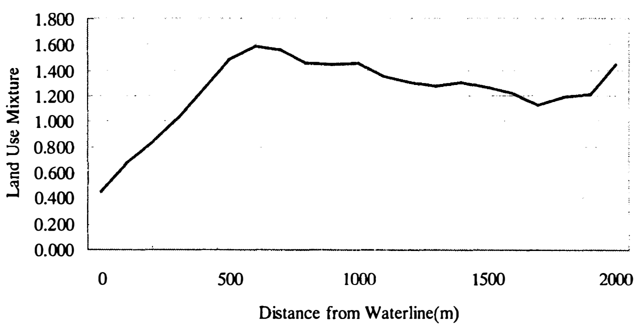

Figure 8. Distance from Waterline and Land Use Mixture

2- Distance from Green Park (Open Space)

This variable was correlated against existing land use (figure 9) and population density (Figure 10). The results show that many people live in the areas close to open space, showing that open space is distributed evenly in the residential districts of the target area.

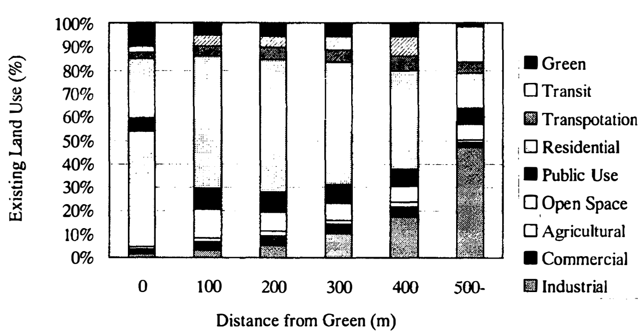

Figure 9. Distance from Green Park and Existing Land Use

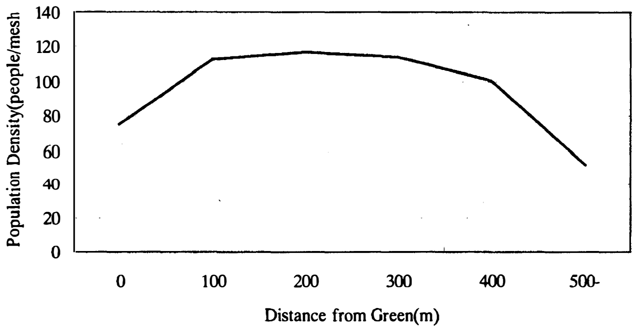

Figure 10. Distance from Green park and Population Density

3- Landfill History

This variable was correlated against existing land use (Figure 11), population density (Figure 12), rail access (Figure 13), road access (Figure 14), regional planning (Figure 15) and land use mixture (Figure 16).

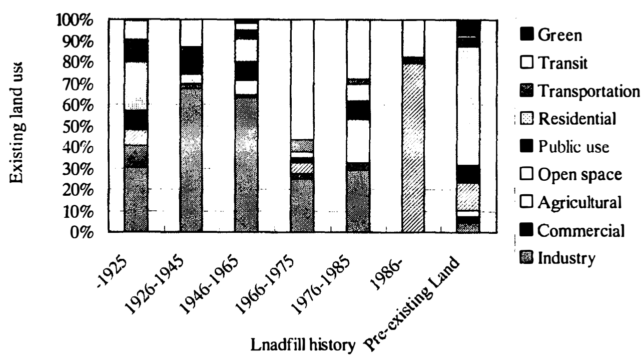

Figure 11. Landfill History and Existing Land Use

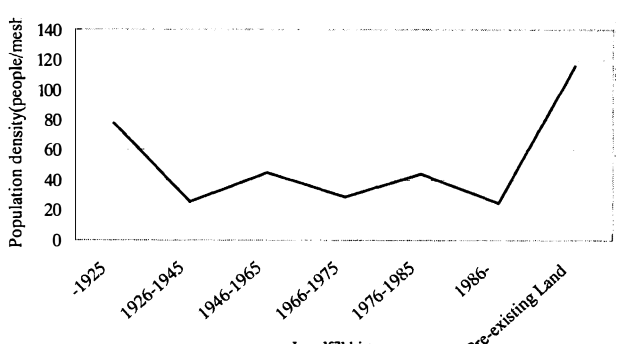

Figure 12. Landfill History and Population Density

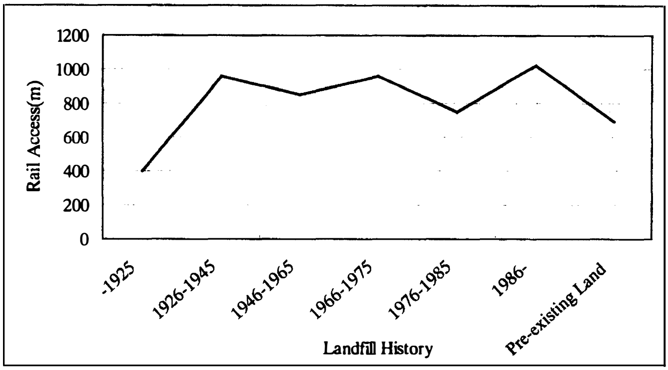

Figure 13. Landfill History and Rail Access

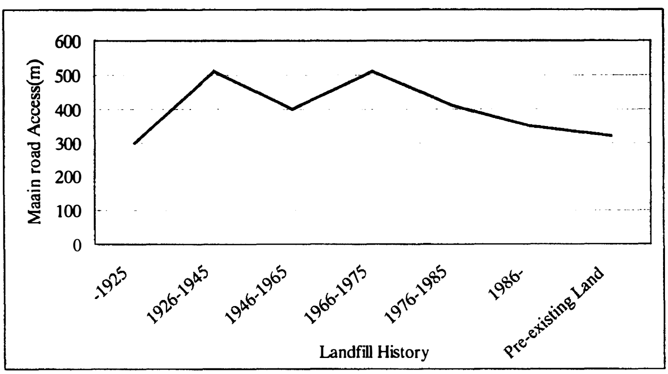

Figure 14. Landfill History and Main Road Access

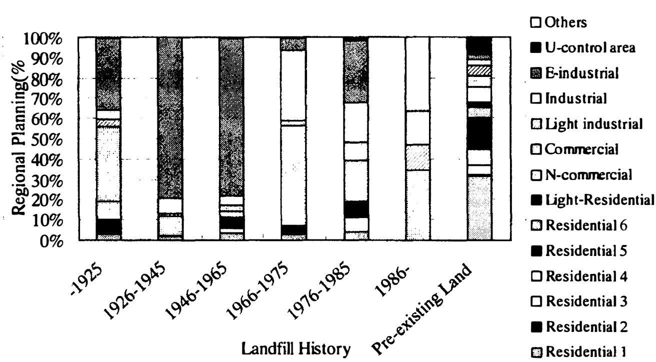

Figure 15. Landfill History and Regional Planning

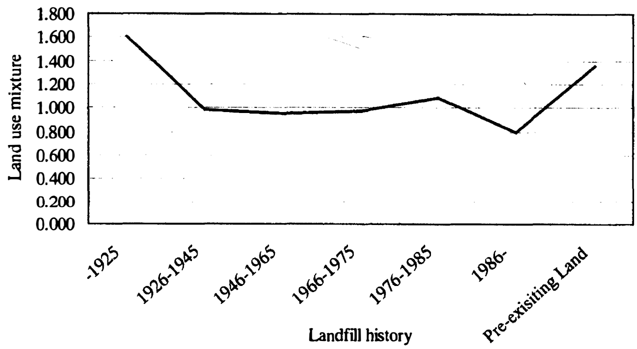

Figure 16. Landfill History and Land Use Mixture

As can be seen from the results, industrial use decreases, and open space increases in the newer landfill areas. Open space is especially plentiful in areas developed after 1976. Population density is low in all the landfill areas, with the exception of those landfilled before 1925. Road and rail access is good in the areas landfilled before 1925, and also in the areas consisting of pre-existing land, but is poor in all other areas. Looking at land use designations, the results show that new industrial designations, with the exception of the light industrial category, decrease after 1976. Commercial designations, on the other hand, increase after 1966.

Regional Planning	Land Use Mixture
Light Residential	1.889
Light Industrial	1.872
Commercial	1.634
Residential 5	1.547
N-commercial	1.485
Industrial	1.462
Residential 4	1.419
Residential 3	1.374
Residential 6	1.272
Residential 1	1.244
U-control area	1.177
Others	1.013
E-industrial	0.770
Residential 2	0.730

4- **Regional Planning**

This variable was correlated against actual land use (Figure 17), land use mixture (Table 5). road access (Figure 18) and rail access (Figure 19). The results indicate that land use is more flexible is areas designated as light industrial, residential or commercial than in other areas. Rail and road access are best in the commercial designations, followed by residential and industrial.

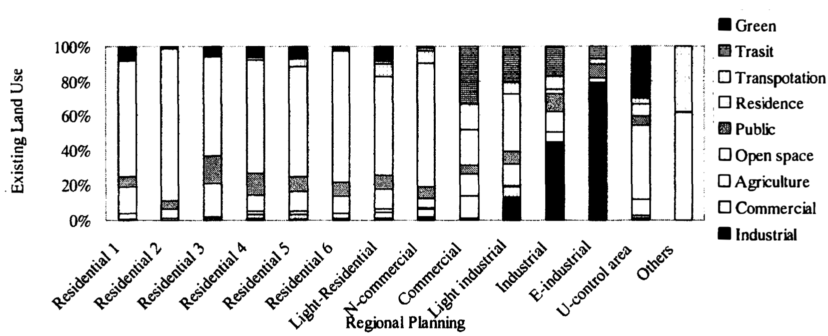

Figure 17. Regional Planning and Existing Land Use

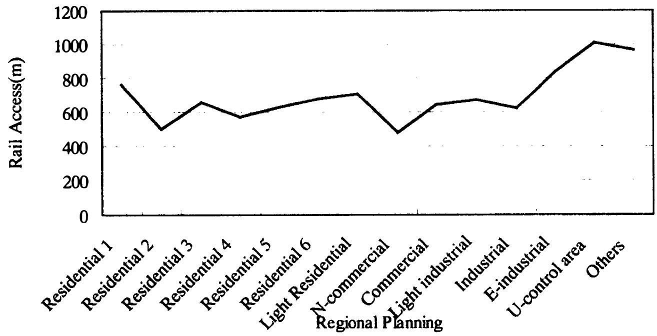

Figure 18. Regional Planning and Rail Access

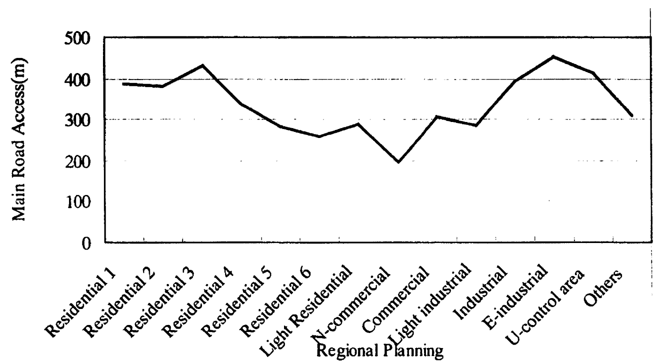

Figure 19. Regional Planning and Main Road Access

CONCLUSION

The results of our research can be summarized as follows:

1- Residential areas and population density are low within 1300 meters of the coast.

2- Road rail access, open space and other urban amenities are poorly developed within 700 meters of the coast.

3- The demand for industrial land decreased after the oil shock of 1978, and there is no actual industrial use in areas landfilled after 1986. In terms of regional planning, there are still some industrial designations in the newer landfill, but light industrial designations have increased, and there has been little or no new demand for industrial facilities. Open space, on the other hand, has increased in the areas landfilled after 1986.

4- Areas designated as light industrial or semi residential have flexible rules for land use, and thus show a high level of land use mixture.

Yokohama is considered to be a representative port city in Japan. Our research, however, showed that the target area as a whole, with the exception of the central Yokohama district, affords very little public access to the waterline. In this sense it is typical of Japanese urban waterfront regions.

The central Yokohama district with good coastal access supports a population of only about 130,000. For the remaining residents and workers in the target area, the coast is much further removed than the actual physical distance indicates.

Most of the coastline in the target area is dominated by heavy industrial facilities that were a major driving force in the high growth years of the postwar economy. Today, however, growth has slowed considerably, and socio-economic needs have changed dramatically. The demand for heavy industry, in particular, has decreased greatly, while the demand for open space, green areas and urban amenities has increased correspondingly, as seen in the flexible use light industrial areas that have grown since the oil shocks of the 1970s.

Future regional planning should take these changing demands into consideration. Flexible land use designations should seek to prevent wasted space, improve the living and working environment, and help to stimulate the economy.

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RISK ASSESSMENT OF MARINE CASUALTY OF OIL TANKER

Han-Jin Lee, Moonjin Lee, In-Young Gong, Jin-Whan Kim and Chang-Gu Kang

Korea Research Institute of Ships and Ocean Engineering
Taejeon, KOREA
hanjlee@mailgw.kimm.re.kr

ABSTRACT

If serious oil spill occurs near shorelines, its impacts on the natural environment and society are immeasurable. Therefore, to draw up plans for new maritime traffic systems, it is necessary to quantitatively assess the safety of the shipping-traffic environment. In this paper, authors try to assess the marine traffic environment from the viewpoint of the degree of risk. First, the marine traffic flow simulation is carried out to get the information on the congested, thus dangerous, region. The simulation is carried out by some statistical methods based on the wide investigation of marine traffic environment, from which the degree of congestion is assessed. Next, the result of oil spill at specific location is estimated by oil spill simulation method. The quantified degree of congestion reasoned by this method provides much information necessary for the design and the evaluation of marine traffic environment.

INTRODUCTION

If serious major oil spill occurs near shorelines, its impacts on the natural environment and society are immeasurable. Therefore, to draw up plans for new maritime traffic systems, it's necessary to quantitatively assess the safety of the shipping-traffic environment. In this paper, as an application of such an approach, authors try to assess the marine traffic environment of Inchon harbor area from the viewpoint of the degree of congestion. Inchon is the nearest harbor to Seoul, the Capital of Korea. And, a new harbor is planned to be constructed in this area for Seoul and near cities as well as a canal between Seoul and Inchon, a new marine airport and so on. Therefore, it is expected that there will be heavy marine traffic in the near future.

Fist of all, the marine traffic flow simulation is carried out to get the information on the congested region. The simulation is carried out by some statistical methods based on the wide investigation of marine traffic environment. In order that the motions of ships may be more realistic, the algorithms of collision avoidance system are used in the simulation. The degree of congestion to express the difficulty in ship handling is assessed by analyzing the simulation results. Here, the degree of congestion means the difficulty felt by navigators as well as the volume of marine traffic.

Finally, this assessment method is applied to the target area where there are main routes of oil tankers. And the result of oil spill at specific location is estimated by oil spill simulation method. In the oil spill simulation, advection is computed by the sum of tidal and wind-driven currents and turbulent diffusion is modeled by random walks process.

MARINE TRAFFIC FLOW SIMULATION

Simulation Conditions

Occurrence of Ships

In the first place, the occurrence conditions of ships must be considered to carry out the traffic flow simulation. These conditions are described on the basis of Origin-Destination (OD) of various ships navigating in the area. An OD is composed of starting line, ending line and fairway.

Generally, the time intervals between ships that pass any line on a fairway can be modeled by exponential distribution function (Nakamura, 1996). So, the time intervals between occurrence of ships on the starting line are expressed by the exponential distribution function. Next, the distribution of trajectories of ships on an OD of real world are approximated by the normal distribution (Nakamura, 1996). Therefore, in this paper, the occurrence positions of ships on the starting line are give by the normal distribution. Furthermore, the length and the speed of the ship are determined by using the normal distribution.

Equations of Motion

Equation (1) shows the equations of motion to describe the maneuvering and accelerating motions of a ship.

$$\begin{aligned} &T \cdot \ddot{\varphi} + \dot{\varphi} = K \cdot \delta \\ &(m + m_x) \cdot \dot{u} = \tfrac{1}{2} \rho S_A C_T (u_T^2 - u^2) \end{aligned} \tag{1}$$

In the marine traffic flow simulation, to be effective in calculation time, the equations of motion must be simple. The precise representation of maneuvering motion of each ship is not important. So, Nomoto's KT model is used for the simulation. In the first equation, K and T are the maneuvering coefficients representing the maneuvering characteristics of ship. And, another equation is taken into account to consider the speed variation of ship. In the equation, m_x is added mass and u_T is target speed.

Collision Avoidance Maneuver

To implement the collision avoidance maneuver, the algorithms of collision avoidance system are used in the simulation.

Generally, the collision avoidance maneuver can be divided into three steps. The first step is when a collision avoidance action is started. The second is what action is carried out. And the last is when the action is ended. The first and last steps require the information of degree of collision risk that is defined for a given situation. In other words, a collision avoidance action starts when the degree of collision risk exceeds a given criterion. And the action ends if the degree decreases below an another criterion. In this paper, Hasegawa's method is used to reason the degree of collision risk, where the degree of collision risk is assessed by fuzzy reasoning method using TCPA and DCPA as input variables (Hasegawa, 1987).

When choosing an avoidance action, the size of selected action as well as the degree of collision risk has to be considered. The degree of preference of maneuver indicates the size of the action. The larger is the action, the smaller is the degree of preference. In this paper, Nakamura's method is used to calculate the degree of preference. Equation (2) shows the degree of preference of maneuver X_i (Nakamura, 1996). In the equation, ΔC means course change and ΔV is ratio of changing speed. The degree of collision risk and the degree of preference have values between 0 and 1.

$$Pb(X_i) = e^{(-a_C \cdot \Delta C)} \cdot e^{(-a_V \cdot \Delta V)}$$
$$a_C = \begin{cases} 0.0190 & \text{(right)} \\ 0.0260 & \text{(left)} \end{cases} \tag{2}$$
$$a_V = 0.0456$$

Usually, a ship takes the action with the maximum degree of preference among all actions whose degree of collision risk is less than a given criterion. If such actions don't exist, the minimum risk action is taken. Furthermore, if all actions have the maximum value of the degree of collision risk, the action with the maximum DCPA is taken (Lee, 1997).

Degree of Congestion

Blocking Coefficient as an Index of Potential Risk

When there is a high risk despite of all maneuvers, it's difficult for navigator to decide which maneuver to take to avoid collision in such a traffic environment. Such a judgement is closely related with risk and preference of the selected maneuver. So, for the degree of congestion on the marine traffic environment, the degree of preference weighted by the degree of collision risk is used. This index is called Blocking Coefficient, *BC*.

Equation (3) shows the definition of *BC* (Nakamura, 1996). Where, X_i is a maneuver composed of course change and speed change. $R(X_i)$ is the degree of collision risk of the maneuver. And $Pb(X_i)$ is the degree of preference.

$$BC = \frac{\sum_{i=1}^{m} R(X_i) \times Pb(X_i)}{\sum_{i=1}^{m} Pb(X_i)} \tag{3}$$

In order to assess the degree of congestion in the entire region, statistical methods are needed. First, during the traffic flow simulation, the *BC* values of all ships are calculated at regular intervals. Then, the target area is divided into meshes. Finally, I_{BC} is calculated for each mesh, which is the rate of the number of steps where *BC* values are larger than a given criterion to the number of all steps. In this case, the *BC* value of a mesh is the largest one for the *BC* values of all the ships existing in the mesh.

Subjective Judgement Value as an Index of Embodied Risk

The *BC* is the degree of congestion felt by navigator before a pertinent maneuver is taken. On the contrary, after a maneuver is carried out, the degree of collision risk felt by navigator can be used as an another index for the degree of congestion.

For this, the degree of collision risk *SJ* suggested by Hara is used. He used the fuzzy method to reason the degree of collision risk. The relative change of bearing and the relative distance are used as input variables (Hara and Hammer, 1990, 1993). The *SJ* values are from -3 to 3. The *SJ* value of 3 indicates the extremely safe situation, where as the *SJ* value of -3 indicates the extremely dangerous situation.

Like *BC*, *SJ* value can be integrated for each mesh to assess the risk for the entire region, which is shown in equation (4) (Hara and Nakamura, 1995). In the equation, *SJ'* indicates the *SJ* value under a threshold value. Where, *m* is the number of *SJ* under the threshold value in a mesh. And *n* is the number of total steps.

$$I_{SJ} = \frac{\sum_{k=1}^{n}\sum_{l=1}^{m}\left|SJ'_{kl}\right|}{n} \qquad (4)$$

OIL SPILL SIMULATION

Oil spill model concept used in this paper is shown in Figure 1. Spilt oils on the sea are advected by environmental flows and diffused by the oil diffusion process (Hong and Lee, 1998). The environmental flows mean tidal currents, wind-driven currents, oceanic currents and so on. And, diffusion process is separation of oil particles by turbulence, wave, spreading and emulsification. Total mass of the spilt oil is determined by evaporation and solution, biochemical process and sinking (Burtler et al., 1976). Through this procedure, distribution of spilt oil is simulated.

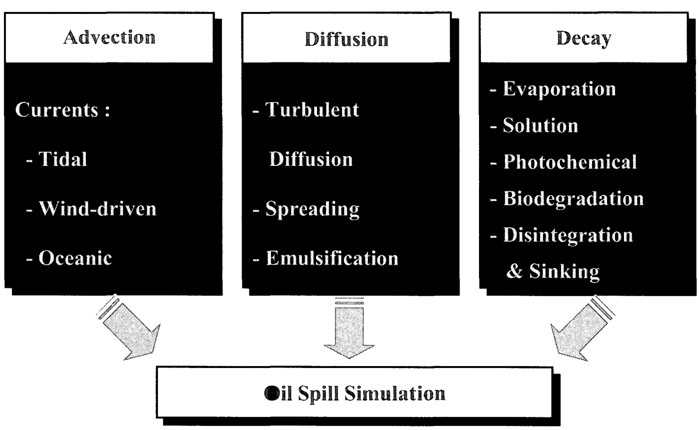

Figure 1. Oil Spill Model

In the oil spill model, tidal and wind-driven currents are employed in computation of advection of environmental flows. Tidal and wind-driven currents are computed by solving continuity and momentum equations. Diffusion process is represented by random walk process (Lee and Kang, 1997). And, decay of the oil is simulated by multi-process with three components. The parameters of oil spill model adopted by authors are summarized in Figure 2.

Currents

Tidal and wind-driven currents :
Computed by solving continuity & momentum equations

Diffusion

Simulated by using random walks process

Decay

Apply multiform decay condition of oil
- Evaporation & Solution : 30% (7 days)
- Photochemical & Biodegradation : 35% (100 days)
- Disintegration & Sinking : 35% (365 days)

Figure 2. Parameters of Oil Spill Model

SIMULATION RESULTS

The target region is near Inchon harbor. Figure 3 shows the target environment.

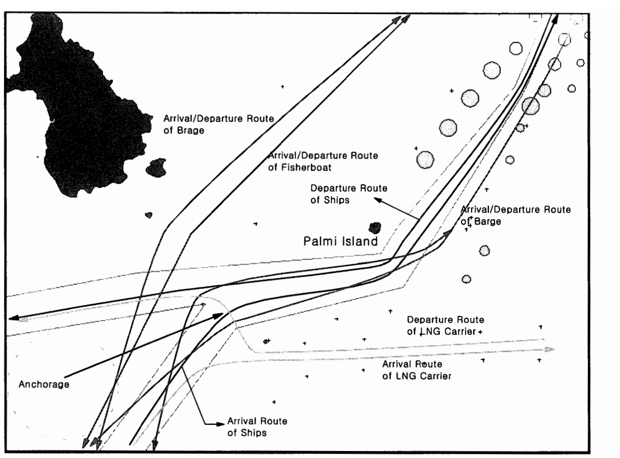

Figure 3. OD Definitions of Inchon Harbor

In the figure, OD definitions of the region are the arrival and departure routes of barges, LNG carriers and so on. In the simulation, the fishery boats are ignored. In the case of LNG carriers, they are considered however their influence on the results is negligible because the traffic density of LNG carrier is very small. The dangerous goods carriers like oil tankers share the same route with general cargo ships.

The traffic flow simulation was performed during 60 hours. The degree of congestion was analyzed from the simulation results at an interval of 10 seconds. Figure 4 shows the trajectories of ships for one hour in this area. During the simulation, 1005 barges, 519 dangerous good carriers, 22 LNG carriers and 103 other ships occurred.

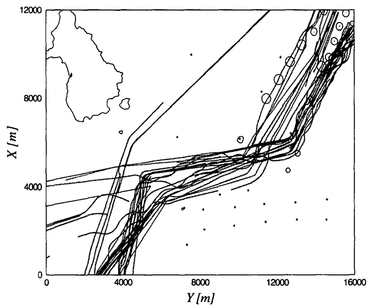

Figure 4. Trajectories for One Hour

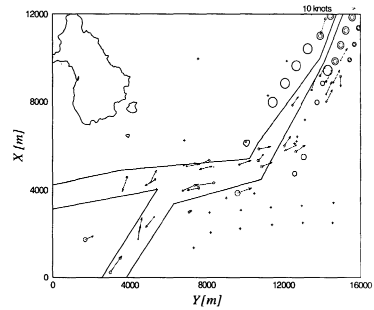

Figure 5. Example of Distribution of Ships

Figure 5 shows the instantaneous distribution of ships at some moment. In the figure, the arrow indicates the magnitude and the direction of ship speed. And the circles indicate the positions and the sizes of ships. The large circles of upper side represent the anchorages.

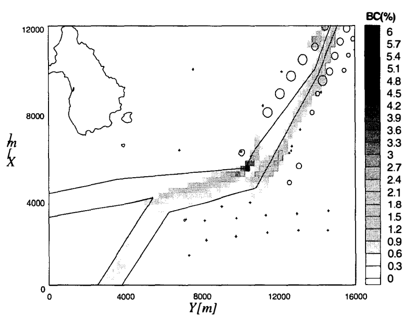

Figure 6. Degree of Congestion I_{BC}

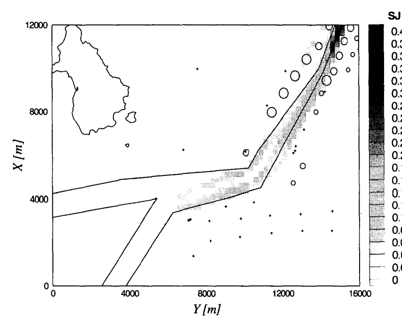

Figure 7. Degree of Congestion I_{SJ}

Figure 6 shows I_{BC} distribution from the viewpoint of dangerous goods carriers. In the figure, the congested areas are shown near Palmi Island and northern anchorages. Near Palmi Island, the routes of general cargo ships intersect the routes of barges. And there exists a bend in the fairway. So the degree of congestion is high in this area. In the case of northern part, because the width of the fairway becomes narrow and because ships exist at anchorage, the degree of congestion is high.

Figure 7 shows I_{SJ} distribution from the viewpoint of dangerous goods carriers. Unlike the I_{BC} distribution, the values near Palmi Island are not high. When reasoning SJ value, the relative change of bearing is used. On the bent part of fairway, the large change of course increases the relative change of bearing. In the reasoning of SJ, the larger is the relative change of bearing, the smaller is the SJ value. So, in the case of I_{SJ}, the degree of congestion is relatively low near Palmi Island. The results at the northern part are similar to those of I_{BC}.

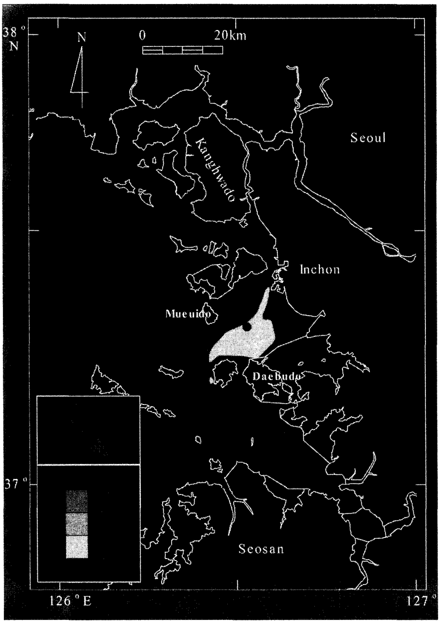

Figure 8. Simulated Oil Spilt Area in Winter

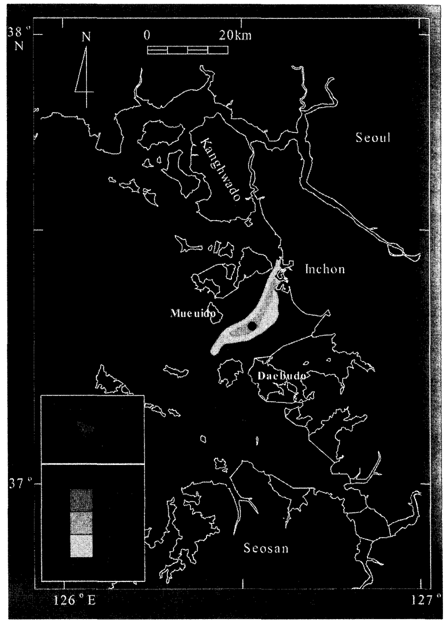

Figure 9. Simulated Oil Spilt Area in Summer

From the results of the marine traffic flow simulation, it is shown that the area near Palmi Island is very congested and high-risk zone. Therefore this area can be assumed to be most probable area of marine casualty of oil tankers navigating Inchon area. In order to estimate the marine environmental damage by spilt oil from a broken tanker, oil spill simulation was carried out.

Simulated oil spilt area is represented in Figure 8 and Figure 9. Here, spill duration is 12 hours and run time is 10 days. Figure 8 and Figure 9 show the distribution of spilt oil in winter and in summer, respectively. The black circle in the figure is the accident point near Palmi Island.

The results of oil spill simulation show that the marine casualty of dangerous goods carrier may cause both serious ecological damage to coastal environment and the possibility of interrupting marine traffic flow in this area. This calculation is an example of assessing the safety of oil tanker routes. By these kinds of calculations, the necessity of new fairway and etc. as an effective tool to reduce the risk can be justified.

CONCLUSIONS

In this paper, authors developed the reasoning method of the degree of congestion. And it was carried out that the estimation of marine environmental damage on the area that is expected to be very congested.

The quantification of relative maneuvering difficulty like the degree of congestion may provide much information necessary for the design and the evaluation of marine traffic environment. Also, the quantification can provide useful information in planning the management of marine pollution.

The indices proposed in this paper have meanings in relative sense. The absolute value of index itself is meaningless. The index having physical meaning need to be developed. And, the relationship between the degree of congestion and the probability of marine casualty need to be developed further.

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WHAT HAS HAPPENED AFTER *NAKHODKA*'S OIL SPILL

Nobuhiro Sawano

Seiryo Women's Junior College
Kanazawa, Ishikawa, JAPAN
sawano@seiryo.ac.jp

SUMMARRY

On January 2nd, 1997, the Russian tanker *NAKHODKA* was carrying approximately 19,200 kiloliters of heavy C oil as cargo and proceeding from Shanghai to Petorpavlovsk. She was broken into two parts by very high waves and strong wind some 100 km off the Oki Island of Japan. Over 8,600 kiloliters of cargo was spilled out of the ship after this accident. Most part of the spilt oil was drifted ashore and brought about severe damage to marine lives and fisheries. In Japan, nation-level contingency programs for such a large scaled oil spill particularly for the coastline has not been prepared, so we have had to face so many problems caused from the lack of unified recovery strategies.

THE OUTLINE OF THIS ACCIDENT

On January 2nd, 1997, the Russian tanker named *NAKHODKA* was navigating towards Petropavlovsk-Kamchatski in the Sea of Japan carrying 19,221 kiloliters of heavy C oil with her. She broke into two sections in the heavy sea with 8 meters effective wave height approximately 100 kilometers off Oki Island, and spilled approximately 8,660 kiloliters of oil (Sao, 1998). The official figure of 6,240 kiloliters (Ishikawa Prefectural Government, 1998) of spilled oil does not include the oil that was spilled out of the *NAKHODKA*'s bow section during subsequent drifting and grounding. The major section of the ship sank to the sea floor of 2,500 meters, with about 10,000 kiloliters of oil remaining in her tanks. This oil is still leaking today. The remaining bow section of the ship turned upside down and drifted five days in the current, until waves and wind finally grounded it on the coast of Mikuni Town, Fukui Prefecture on January 7th (see Figure 1).

CAUSE OF THE ACCIDENT

The cause of the accident was investigated through an underwater survey of *NAKHODKA* by ROV (Remotely Operated Vehicle) which made a comprehensive check of the grounded bow section. The survey concluded that the *NAKHODKA* had been very poorly maintained and that her strength had decreased to two thirds of the original construction strength. Furthermore, the cargo oil was not loaded properly. The arrangement was so inadequate that the resulting longitudinal bending moment was twice the value corresponding to the normal cargo oil arrangement specified in the ship's operation manual (Sao, 1998). Along these reasons, severe winter weather in this district must have triggered this accident. In this district, we usually have "typhoon weather" from December to mid February on.

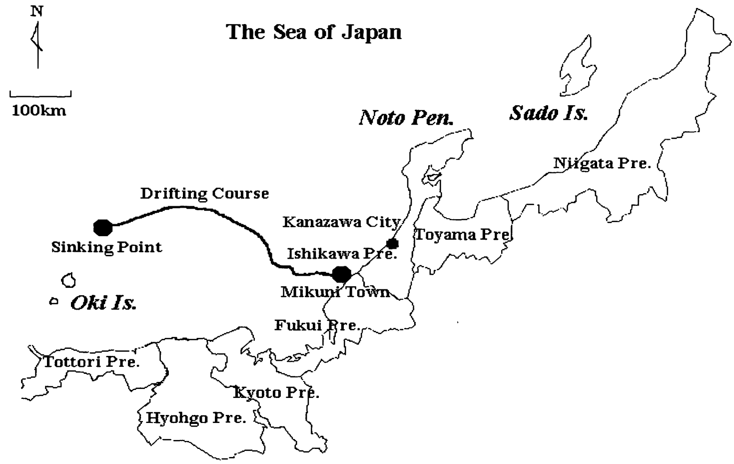

Figure 1. Location of the Accident

MEETING THE NEEDS FOR EVERY MOMENT

The oil affected more than 1,300 kilometers of shoreline including over 9 prefectures and 88 cities and towns. Japan had not prepared nation-leveled contingency program for such oil pollution. As a result, countermeasures were taken to meet the needs of every moment with little formal planning. Over one million volunteers (unit: person·day) from all over Japan participated in oil recovery works in the cold winter weather. However, they concentrated their efforts on mainly Mikuni Town where the bow part had grounded and publicized the damage at this one site leaving some heavily contaminated shorelines without sufficient clean up.

Solvent *ISOPAR H* in Mikuni Town

Many volunteer workers were gathered in Mikuni Town and very ill-conceived clean-up activities were carried out. They used harmful solvents to wash off the oil from polluted rocks and stones. *EXXON*'s *ISOPAR H* was actually used not only for washing the clean-up crews' clothes and hands but also for wiping the oil off of the rocks. An important fact is that Mikuni Town's officials explained *ISOPAR H* was very "earth- friendly detergent" and they recommended volunteers to use it for recovery works. Some volunteer workers washed their hands and even washed their faces with it because "SENZAI" means detergent in Japanese (see figure 2).

Mikuni Town government bought at least 2 kiloliters of *ISOPAR H* and all of them were used. Beside *ISOPAR H*, so many kinds of solvents were used for clean-up works through the fishermen unions or some other volunteer groups.

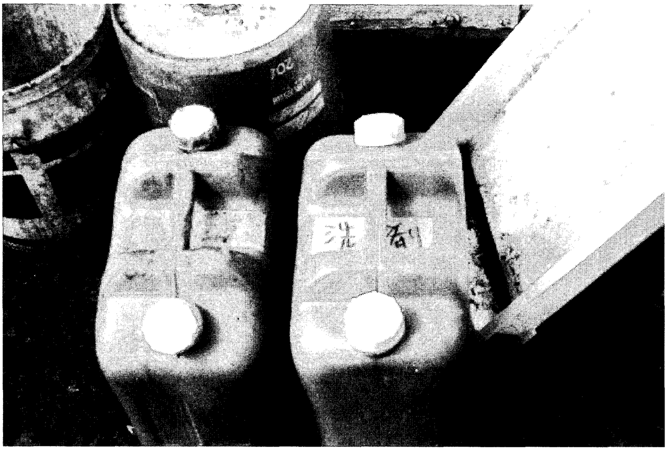

Figure 2. The Container of *EXXON ISPAR H* Used for Wiping Oil

SENZAI (洗剤) means detergent

Since then, another idea was introduced by some people in the local community. The idea appears substantially more dangerous to the people and more damaging to the marine lives: high pressure washing with *ISOPAR H*. High pressure washing with sea water were widely done around Mikuni Town. One fisherman union in Mikuni Town has been thinking of using the same high pressure machine to wash off the oil with *ISOPAR H*. However, concentrated aerosol content of *ISOPAR H* is harmful to people; its material safety data sheet (MSDS) states that people may be killed when the concentration of *ISOPAR H* exceeds 1,000 PPM in the air. *ISOPAR H* is also a flammable solvent. High pressure washing with *ISOPAR H* has been temporarily stopped through the efforts of one of volunteers, who had persuaded the fishermen to wait. However, there were some emotions among fishermen and other local people, in which anything dangerous could happen.

Sand Beaches in Kaga City

About 4 kilometers long of beautiful beach from Katano to Shioya in Kaga City (location is shown in Figure 3), is another example of the place where inadequate countermeasures were initiated. Soon after the spill, local public works personnel started to clean up the beached oil with about 70 bulldozers and other power construction machines. Because of the inability of the equipment to separate oil and sand, they ended up leaving over 18,000 cubic meters of oil mixed with sand (Ishikawa Prefecutral Government, 1998).

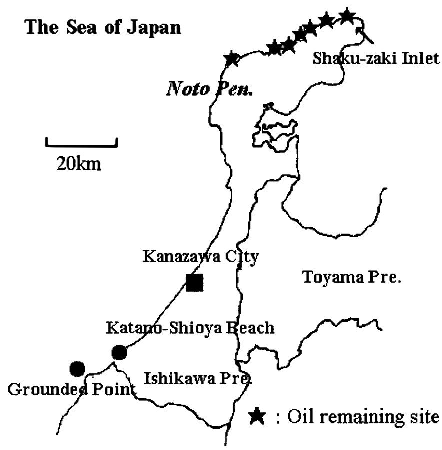

Figure 3. Location of Oil Impacted Sites in Ishikawa Prefecture

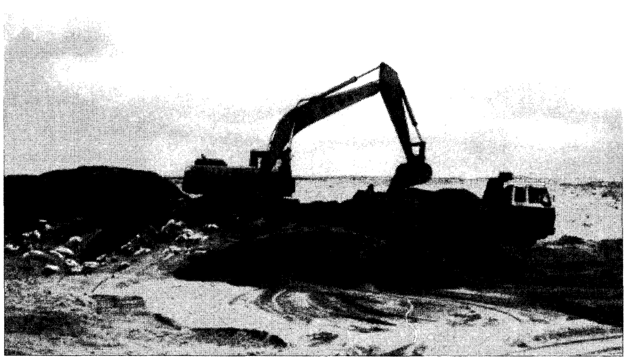

Figure 4. Oil Contaminated Sand “Mountain” in Shioya Beach

Figure 5. Burying Oiled Sand in Industrial Waste Dump

On January 8th 1997, tremendous amount of oil polluted Katano to Shioya. Only three days later, recovery works were finished but made up about 30 oiled sand "mountains" on these beaches (see figure 4). In April 1997, only two sand mountains in Shioya were carried to bury in a newly built industrial waste dump site (see figure 5). About 4,000 cubic meter oiled sand was buried in this dump, so the official figure 18,000 cubic meters is too small considering the number and scale of the oiled sand mountains made up on these beaches.

Figure 6. Iso-sumire (*Viola grayi*) at Shioya

From mid February on, local people and volunteer workers tried to sieve the tarred oil from the oiled sand but they were able to process only 377 cubic meters of the contaminated sand (Kaga Heavy Oil Volunteer Center, 1997). Local government said that they left more than 10,000 cubic meters of oiled sand and buried on the beach (Ishikawa Prefectural Government,1998). But this figure has to be much larger.

Today, significant quantities of oiled sand continue to appear on the surface and this is sure to have a harmful effect to habitat for shoreline vegetation. The activity of heavy machine cleaning on the beach directly damaged many plants resulting in large-scale erosion that continues even 14 months after the spill.

Both Katano and Shioya are well known as a valuable plant-habitat. As of May 1998, 25 plant-species have been confirmed (see Table 1). In these areas, many coastal pristine environments with unique coastal forms of life remained before the oil spill. Hamabengiku, a kind of chrysanthemum (*Heteropappus hispidus* ssp. Arenarius) and Ishosumire, a kind of violet (*Viola grayi*, see Figure 6), endangered plants all over Japan.

Table 1. List for Plant Species Raising on Katano and Shioya

Japanese Name	Botanical Name	Tree Plant
Hai-nezu	Juniperus conferta	+
Gyougi-shiba	Cynodon dactylon	
Ke-kamonohashi	Ischaemum anthephoroides	
Koubou-mugi	Carex kobomugi	
Koubou-shiba	Carex pumila	
Okahijiki	Salsola komarovii	
Aotsuzura-fuji	Cocculus trilobus	
Hamahatazao	Arabis stelleri var. japonica	
Nemunoki	Albizia julibrissin	+
Akigumi	Elaeagnus umbellata	+
Anama-sumire	Viola mandshurica var. crassa	
Iso-sumire	Viola grayi	
Mematsuyoigusa	Oenothera biennis	
Hamaboufu	Glehnia littoralis	
Hekusokazura	Paederia scandens	
Nenashikazura	Cuscuta japonica	
Amerika-nenashikazura	Cuscuta pentagona	
Hama-hirugao	Calystegia soldanella	
Hamagou	Vitex rotundifolia	+
Funakisou	Scutellaria strigillosa	
Un-ran	Linaria japonica	
Kawarayomogi	Artemisia capillaris	
Nekonoshita	Wedelia prostrata	
Hamabe-nogiku	Heteropappus hispidus ssp. Arenarius	
Hamanigana	Ixeris repens	

Besides these two plant species, Iso-komori-gumo (*Lycosa isikariana*), Kisuji-tsuchi-sugari (*Cicindela arenarias*) and Kawara-awafuki-bachi (*Dienoplus tumidus*) are also endangered species of spiders and bees, whose habitats strictly depend on the clean sand beach in these areas.

For the plant species listed in Table 1, tree plants are very sensitive to treading. Many of them were severely damaged by the traffics of heavy construction machines while recovery works were done. Tree plants play a great role in protecting sand beach from erosion. Both Katano and Shioya are facing big scale sand erosion today.

From Noto Peninsular

Much oil was also stranded on the long shoreline of Noto Peninsular. About 50,000 kiloliters of oil and waste were recovered from the sea and shorelines in this accident, only 14 % of which was recovered on the sea by the fishing boats, grab-bucket barges, naval vessels, and skimmers. It was because the heavy winter weather and large oil recovery ships could only work under 2.5 meter effective wave height.

Shaku-zaki Inlet in Suzu city is the most affected place in Noto. Recovery works were executed mainly by the members of Self Defense Forces of Japan. Because of the tidal currency, this inlet is easy to gather floating oil. The inside of this inlet, tidal wetland is developed and has vegetations like *Juncus gracillimus* and *Carex scabrifolia*. Rocks are "sheltering" this wetland and "isolating" it from the sea. Once oil is carried "over" to these rocks by strong wave and wind to the wetland, it never goes back to the sea.

Actually, along the fringe of the wetland in this inlet, there is still remaining about one kilometer long and 50 – 100 cm meter deep in the sediment (see figure 7). Surface of oil has become "asphalt pavement". But inside the pavement, even today, oil is still gooey.

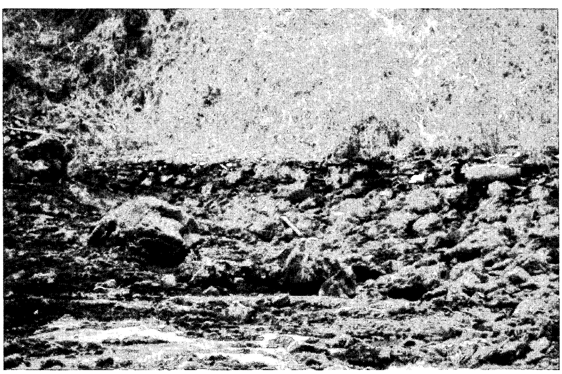

Figure 7. Shaku-zaki Inlet in Noto Peninsular

SOME CHEMICAL FEATURES OF *NAKHODKA*'S CARGO

Heavy C oil carried by *NAKHODKA* has very typical chemical components. *NAKHODKA*'s oil contains about 100 times high concentration of aromatic hydrocarbons such as benzo(a)pyren comparing with heavy C oil usually used in Japan (Takada, 1998). High molecular weight component of oil is said to be hard to degrade naturally. And also, benzo(a)pyren is a typical environmental endocrine disrutptor (Keith, 1997). These components are easily concentrated through the marine ecosystem.

Shaku-zaki or other oil remaining sites in Noto Peninsular are well known as good fisheries and for sea food such as selfish and sea weeds. Both local people and sight seeing tourists take sea food as daily works. Local government should forbid entrance to such sites. But no countermeasures have been executed yet.

WHAT ARE PROBLEMS UNDER DISCUSSION?

Japanese Government and private enterprises concerning oil spill have been ignoring making plans for protecting shoreline marine environment. One reason is the Japanese law system. It is so complicated and said to be just like "maze".

Facing *NAKHODKA* disaster, we know the necessity for preparing an NCP (National Contingency Plan). Preceding this project, we have to prepare an ESI (Environmental Sensitivity Index) research for every Japanese coastline as soon as possible. It is clear the fact of the lack of ESI concept and recovery planning based on ESI, resulted many problems occurred after the oil spill. These problems obviously enlarged damages to various kinds of coastal environment systems including human economy. We have to start from this lesson.

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AUSTRALIAN AND NORTH AMERICAN COASTAL AND MARINE TOURISTS: WHAT DO THEY WANT?

Tanya Greenwood and Gianna Moscardo

CRC Reef Research Centre
James Cook University
Townsville, Queensland, AUSTRALIA
Tanya.Greenwood1@jcu.edu.au

ABSTRACT

A critical component of managing coastal and marine tourism is understanding patterns of tourism use of these areas. One of the key factors influencing this tourism use is tourists' motivations. In other words, tourists will seek coastal and marine tourism products which they believe will fulfil their needs and provide them with desired benefits. An understanding of coastal and marine tourist motivations provides public sector and protected managers with information about demand for certain types of experience. This can be used to inform decisions about the provision of access and the control of activities. For tourism managers in the private sector information on motivations can be used to help develop new products, and adjust existing products to be more successful. This paper will present the results of an analysis of the motivations of Australian and North American coastal and marine tourists. The study involved an examination of both motives for travel in general as well as motives for visiting a specific marine environment. The data was collected from more than 3000 visitors to the Great Barrier Reef. The analyses will be presented in a number of parts which describe and compare the key travel motives for each group along with their specific motives and experiences of the Great Barrier Reef marine environment. Finally, management implications will be discussed.

INTRODUCTION

Understanding patterns of use of an area is a critical component of any coastal or marine area management plan. It has long been recognised that people's motivations are a major influence on where they go and their choice of tourist services and activities (Graefe and Vaske, 1987; Graham, Nilsen and Payne, 1988; Hall and McArthur, 1993; Moscardo, Pearce and Haxton, 1998; Ryan, 1995).

An important component of the effective management of marine tourism is an accurate understanding of visitor motivations. Several studies have demonstrated that managers, particularly of protected and conservation areas, often have mistaken beliefs about the motives of the tourists visiting their areas. A study conducted on one of the islands of the Great Barrier Reef, for example, found that managers underestimated tourist interest in the environment and in nature based educational activities (Pearce, 1988). This is consistent with common stereotypes that tourists are interested only in fun, entertainment, escape and relaxation. In this view of tourists the environment is seen as a pleasant backdrop for activities rather than the central focus of the tourist experience.

In other discussions about tourists there is a similar or related stereotype that domestic or resident tourists are very different to international or foreign tourists. Specifically, it is often assumed that local visitors care more and know more about the visited environment and so will be more interested in the environment and more conservation oriented. Studies comparing different types of tourists and their use of, and reactions to, museums and information centres in the Great Barrier Reef region suggest, however, that this assumption may be inaccurate. In these studies international visitors were consistently found to be more interested in the environment and more critical of the available tourist products (Moscardo, 1992).

The present paper will describe Australian and North American marine visitors in terms of their travel motivations and desired experiences of the Great Barrier Reef. A comparative analysis of these two different visitor groups will then be presented as a way of testing the assumed high environmental consciousness of local or domestic visitors over that of international visitors.

METHOD

The data used in this study was obtained from a total of 3216 surveys which were collected from visitors to the North and Far North Queensland regions. The large collection of data is part of an on-going project by the Cooperative Research Centre for Reef Research to gather and analyse reef visitor information which will assist the managers and stakeholders of the Great Barrier Reef Marine Park to manage and promote the area in an ecologically sustainable manner.

Surveys were administered at various local and regional tourist information centres, attractions and transport terminals, and on-board a variety of commercial reef and island tourism operations. An overall response rate of 80% was obtained.

From this data set, the two visitor groups for the present study were identified and extracted for the analytical purposes outlined giving a sample size for these analyses of 1298. The North American marine visitors comprised of tourists to the Great Barrier Reef region from the United States and Canada and accounted for 28% of the sample. The Australian marine visitors included all inter and intra state tourists to the Great Barrier Reef region and accounted for 72% of the sample.

RESULTS

Visitor profiles

A number of sociodemographic and travel behaviour variables have been suggested as influences on travel motivation. The first part of the analyses examined and compared each visitor group in terms of age, travel party structure and mode of transport used to travel to the Great Barrier Reef region.

The mean age of the Australian domestic visitor group travelling to the Great Barrier Reef was 38 years and the mean age of the North American visitor group was 41 years. As can be seen in Table 1 the Australian marine tourists were significantly more likely to by travelling to the Reef with their spouse or partner (61.3%), and were also more likely to travel with children under 12 years (9.9%). The North American respondents on the other hand were far more likely to by travelling in an organised group/club than were the Australian respondents (11.6% and 4.4% respectively). Table 2 indicates the differences between the modes of transport used by each group to travel to the Great Barrier Reef region. A large percentage of the North American visitor group arrived in the region by plane (65.5%) followed by almost 20 percent arriving by long distance coach. The domestic visitor group, however, were significantly more likely to arrive by private or rental vehicle.

Table 1. Comparison of travel party structure

Travel Party Structure	**Percentage of Respondents**	
	North American Marine Tourists	Australian Marine Tourists
Travelling with spouse/partner	53.7%	**61.3%**
Travelling alone	15.1	11.9
Travelling with friends	18.2	20.6
Travelling in organised group/club	**11.6**	4.4
Travelling with child(ren) under 12 years	6.3	**9.9**
Travelling with child(ren) 12 years & over	6.8	6.5
Travelling with other relatives	5.1	6.8
Travelling with parent(s)	4.8	5.7
Travelling with business associates	4.0	2.8

NB The figures which appear in bold are indicative of statistical significant differences at the 0.05 level, based on chi-square analyses.

Table 2. Main form of transport to the Great Barrier Reef region

Transport Mode	**Percentage of Respondents**	
	North American Marine Tourists	Australian Marine Tourists
Plane	**65.5%**	51.9%
Private vehicle	3.6	**23.9**
Long distance coach	**18.4**	3.4
Rental vehicle	4.9	**10.8**

NB The figures which appear in bold are indicative of statistical significant differences at the 0.05 level, based on chi-square analyses.

General Travel Motivation

Respondents were asked a number of questions relating to their motives for both travel in general and travel specifically to the Great Barrier Reef marine environment. In order to capture general travel motivations, respondents were asked to rate a variety of motivational items according to their importance in motivating the respondent to travel in general. These items were then factor analysed to produce five general motivation factors upon which respondents place varying significance. The results of the factor analysis are displayed in Table 3.

Table 3. Results of the factor analysis of general travel motivation

Motive statements	**Cultural Experience** (21% of variance)	**Excitement / Adventure** (15% of variance)	**Relaxation/ Escape** (10% of variance)	**Family/VFR** (8% of variance)	**Status** (6% of variance)
Seeing a culture different to my own	0.88				
Unique/different cultural groups	0.84				
Seeing a foreign destination	0.73				
Learning new things	0.68				
Being daring and adventurous		0.78			
Finding thrills and excitement		0.74			
Being physically active		0.73			
Having fun		0.57			
Getting away from the demands of home			0.72		
Opportunity to get away from it all			0.68		
A change from a busy job			0.66		
A simpler lifestyle			0.59		
Being together as a family				0.89	
Activities for the whole family				0.88	
Going to places my friends have not been					0.78
Talking about the trip after I return home					0.77
Indulging in luxury					0.47

Table 4 shows a comparison of the general travel motivation factors which were most important to each of the marine visitor groups. Independent t-tests were used to examine differences between the two groups. Three significant differences were detected with *cultural experience* being more important for the international visitors and *relaxation/escape* and being with family and friends more important to the domestic visitors.

Table 4. Comparison of general travel motivation factors

North American Marine Tourists		Australian Marine Tourists	
General Travel Motivations	**Mean***	**General Travel Motivations**	**Mean***
Cultural experience factor	**1.5**	Cultural experience factor	2.1
Excitement/adventure factor	1.9	Excitement/adventure factor	2.1
Relaxation/escape factor	2.1	Relaxation/escape factor	**1.9**
Family/VFR factor	2.6	Family/VFR factor	**2.3**
Status factor	2.9	Status factor	2.8

* Mean scores based on a 4-point Likert scale 1= Very important; 2= Somewhat important; 3= Not very important; 4= Not at all important.

NB The figures which appear in bold are indicative of a significant difference in means.

Reef Specific Motivation

In order to compare and analyse the motivations of each group for visiting the Great Barrier Reef in particular, a number of benefits associated with visiting a marine environment were listed for rating purposes. The items *or* benefits were chosen from previously developed and tested recreation motivation scales (Moscardo, Pearce and Haxton, 1998). The motivations of respondent groups for specifically visiting the Great Barrier Reef marine environment are displayed in Table 5. Here, the specific marine *or* reef environment related motives for travelling to the destination are listed in the order, highest to lowest, of the proportion of respondents from each group who rated each motive as *very important.* As can be seen, a significantly higher number of North American visitors indicated that *seeing the beauty of the Great Barrier Reef* (87%) and to gain *a learning/educational experience* (64%) were very important motives for visiting the Reef.

Table 5. Comparison of motivations for specifically visiting the Great Barrier Reef marine environment

North American Marine Tourists		Australian Marine Tourists	
Motivations for visiting the Great Barrier Reef	**Percent** (rated as Very Important)	**Motivations for visiting the Great Barrier Reef**	**Percent** (rated as Very Important)
Seeing the beauty of the Great Barrier Reef	**87%**	Seeing the beauty of the Great Barrier Reef	82%
Seeing coral in its natural surroundings	80	Seeing coral in its natural surroundings	82
Seeing marine life in detail	68	Seeing marine life in detail	64
A learning/educational experience	**64**	Swimming amongst the marine life	60
Being close to nature	62%	Being close to nature	57%
Something new and different	61	Something new and different	57

Table 5 continued

North American Marine Tourists		Australian Marine Tourists	
Swimming amongst the marine life	58	A learning/educational experience	48
Being physically active	39	An opportunity to rest and relax	**45**
Provides excitement	36	Provides a chance to escape	**38**
An opportunity to rest and relax	33	Being physically active	38
Provides a chance to escape	28	Provides excitement	35
An opportunity to be with friends, partners or family	26	An opportunity to be with friends, partners or family	**34**

NB The figures which appear in bold are indicative of statistical significant differences at the 0.05 level, based on chi-square analyses.

Differences in Activities and Responses to the Experience

It was noted in the introduction that motivation exerts a major influence on activity choices and the perceived quality of the experience. The final stage in the analyses, therefore, was a comparative analysis of the activities that North American and Australian visitors to the Great Barrier Reef undertake while visiting the Reef. Table 6 shows the comparison of participation in activities by respondents and Table 7 summarises and compares each group's best features of their visit·to the Great Barrier Reef. The results showed that a significantly higher percentage of North American respondents participated in snorkelling, marine life viewing, scuba diving and overnight cruises. The Australian marine tourists were far more passive with almost all percentages of activity participation to be notably lower than the North American tourists. An exception, however, was the significantly higher percentage of Australian respondents participating in fishing.

Table 6. Comparison of reef activity participation in the Great Barrier Reef marine environment

Reef Activity Participation	**Percentage of Respondents**	
	North American Marine Tourists	Australian Marine Tourists
Swimming	78%	78%
Snorkelling	**80**	70
View marine animals	**77**	49
Glass bottom boat	52	52
Visit Islands	50	51
Scuba diving	**40**	34
Reef walking	29	27
Sailing	25	21
Fishing	13	**24**
Cruise (>1 night)	**22**	14

NB The figures which appear in bold are indicative of statistical significant differences at the 0.05 level, based on chi-square analyses.

Table 7. Comparison of the best features of respondents' visit to the Great Barrier Reef

North American Marine Tourists		Australian Marine Tourists	
Best features	**Percent**	**Best features**	**Percent**
Semi-sub/Glass bottom boat	16%	Semi-sub/Glass bottom boat	20%
Snorkelling	12	Snorkelling	12
Beauty of the Reef	12	Being with family/friends	11
Scuba diving	8	Seeing coral	8
Seeing fish	8	Swimming	8

A comparative analysis between the two visitor groups was also undertaken based on the suggested improvements to the Great Barrier Reef and/or respondents' reef experience. As shown in Table 8, the North American respondents were notably more inclined than the Australian respondents to suggest that visitor numbers be restricted or limited (11% and 8% respectively), that more information and education was needed (9% and 5% respectively), and that visitor impacts be limited or minimised (7% and 3% respectively).

Table 8. Comparison of suggested improvements for the Great Barrier Reef

North American Marine Tourists		Australian Marine Tourists	
Suggested Improvements	**Percent**	**Suggested Improvements**	**Percent**
More time on Reef	20%	More time on Reef	14%
Restrict numbers of visitors	11%	More information/education	8%
More information/education	9%	Limit visitor impacts	5%
Better organisation of activities	8%	Better organisation of activities	4%
Limit visitor impacts	7%	Provide more facilities	3%

IMPLICATIONS AND CONCLUSIONS

The evidence can firstly be examined with regard to stereotypes of international visitors. In this case the North American sample was older, less likely to be travelling with children and more likely to be part of a package tour. Yet these visitors were also generally more active with higher percentages participating in snorkelling and diving. These visitors were also more concerned with learning and with experiencing the environment. By way of contrast domestic Australian visitors were much more likely to fit the stereotype of tourists interested only in sun, sea and relaxation. They were also much less interested in learning about the reef and much less likely to express concern over visitor impacts.

This high level of interest in learning and education and concerns over visitor impacts suggests that international tourists may be a prime audience for minimal impact education programs. Some minimal impact information is provided to tourists, but on the whole the focus of information is on safety and on reef ecology. In a study conducted in the World Heritage rainforests adjacent to the Great Barrier Reef it was found that the bulk of education and information provided for visitors concentrated on rainforest ecology and yet the main

information need identified by the tourists themselves was on ways they could minimise their own impacts on the rainforest. There is growing evidence that both education and minimal impact strategies are important to visitors and both operators and managers have opportunities to provide not only a more enjoyable experience to visitors, but also to influence visitor behaviour
in positive ways.

The motivation profiles for the two groups were consistent with their activity participation. Two differences are worth highlighting in a discussion of management implications. The first is that Australians were more likely to go fishing, while the second is that North Americans were much more likely to seek marine wildlife viewing opportunities. Both of these activities have the potential to be very damaging to the reef environment. Wildlife viewing, in particular, is an activity that managers should closely monitor.

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ASIAN COASTAL AND MARINE TOURISTS: WHO ARE THEY?

Edward Y. J. Kim

Tourism Program/CRC Reef Research Centre
James Cook University
Cairns QLD AUSTRALIA
Edward.Kim@jcu.edu.au

ABSTRACT

The Asia-Pacific region has been, and despite recent economic difficulties, will continue to be a major source and destination for tourism. Much of the tourism product available and sought after in this region is coastal and marine in its nature. An understanding of Asian coastal and marine tourists is therefore a high priority for any marine management organisation. This paper will present the results of a study conducted in Cairns on the far north eastern coast of Australia. The project involved conducting a survey of Japanese, Korean and Chinese speaking visitors to the Great Barrier Reef region. This large scale survey examined a number of different aspects of these visitors and their marine tourism experiences. This profiling these visitors in terms of their demographics, travel patterns and information sources.

The results to be presented will provide both insights in cross cultural differences in coastal and marine tourists and examples of how information about tourists can be used to guide management decisions. In particular the paper will concentrate on using this survey data to develop education programs for these visitors to encourage appropriate behaviour in marine environments and travel.

INTRODUCTION

The highest rates of growth in visitor arrivals into Australia in recent years have been from emerging Asian markets (Kim, 1997). Understanding the diversity and characteristics among visitors from these markets is vital for planning to meet the requirements of the fastest growing source of visitors. Nature-based environmental activities are shown to be the most desirable experiences for holiday travellers to Australia (Childs, 1991; Blamey, 1995). In particular, coastal and marine related activities such as visiting the coastline, beaches, islands, and seeing the Great Barrier Reef, are the most favoured type of activities (Kim, 1996).

The Great Barrier Reef Marine Park obtained World Heritage listing in 1981 (UNESCO, 1998). The Great Barrier Reef extends more than 2000 kilometres along the east coast of Australia, there are over 750 islands included within its boundaries and the Great Barrier Reef Marine Park cover an area of some 350 000km^2. The tourism industry within the Marine Park primarily consists of general day trip boat operators, overnight boat trips, specialist dive trips, and game fishing trips (Burns, 1997).

The Asia-Pacific region has been, and despite recent economic difficulties, will continue to be an important source of visitors to the GBR. Visitors from Japan dominate the pattern of international travel to the far northern section of the GBR and the growth rates for visits from

Korea, Taiwan, Hong Kong and Singapore have been very impressive in recent times. BTR (1998) Figures for international visitors to the GBR are

Table 1: International Visitors to the GBR

Origin of Country	Percent
Japanese	32%
Taiwan/Hong Kong/Singapore	7%
Korea	2%
Europe (Not United Kingdom)	21%
United Kingdom	13%
United States	12%
New Zealand	6%
Other	7%

(Source: BTR, 1998)

There is a growing belief among tour operators that these Asian countries will be critical sources of customers in the future and so they are very concerned with developing appropriate products and promotional campaigns.

The management agencies responsible for the care of the GBR are also interested in further understanding visitors from Asian countries. In particular they are concerned with the need to develop cost effective information or education programs for these visitors. The aim of these education programs would be to improve or enhance the reef experiences for these visitors and to assist in limiting negative impacts by informing visitors about appropriate and minimal impact behaviours.

There is clearly a need for information about these visitors. This need is further highlighted by the fact that few managers, either in the private or public sector, have had experience in dealing with international visitors at all and especially non European international visitors. This lack of experience results in a tendency to discuss Asian visitors as if they were a single homogenous group and to make judgements about Asian visitors based on experiences with Japanese visitors who have had the longest history of visiting the GBR.

The key argument made in this paper was that to manage visitors, both in terms of making sure that their activities have no negative environmental impacts and that they have a positive experience you need to know who they are, what they do and how satisfied they are with the experiences available. Sustainable coastal and marine tourism requires both continuing quality in the environment but also continuing demand for and quality in the tourist products available.

The aim of the research was to examine the socio-demographic profiles, travel behaviours and satisfaction of three groups of reef visitors from Japan, Korea and Taiwan/Hong Kong.

METHOD

Data on other international visitors was also used in this project and this data was collected using a similar survey but was collected from a variety of different boats and operations. This gives one major difference between Asian and other International visitors - that Asian visitors access the reef mainly with big operators and on big boats and arrive in the region as package visitors, while other international visitors are much more likely to be independent travellers and access the reef in a variety of ways.

This is consistent with the way the surveyed visitors booked their reef trips. For 63% of the Chinese visitors, 71% of the Korean visitors, 37% of the Japanese visitors and 20% of the Other International visitors the reef trip was part of an inclusive package tour. By way of contrast 60% of the Other International visitors booked their reef trip either through their accommodation or directly, while this option was used by only 6% of Chinese visitors, 22% of Japanese visitors and 10% of Korean visitors.

The Other International visitors group was made up of 36% Europeans (Not UK/Ireland), 32% United Kingdom and Ireland and 29% from North America.

RESULTS

Throughout the results section the main focus of the analyses was to profile the three Asian groups and to examine and seek to find statistically significant differences between them. The tables provide the information for the three Asian groups as well as for the Other International visitors. This addition allows for a comparison point to determine if the Asian groups are more similar to each other than to the Other International visitors.

Table 2: Demographic Profile of the Samples.

Variable	Chinese	Japanese	Korean	Other International
A. Age				
<21	13%	7%	3%	10%
21-30	30%	48%	39%	32%
31-40	24%	23%	32%	21%
41-50	23%	11%	16%	17%
51-60	8%	7%	7%	12%
61-70	2%	2%	2%	8%
>70	-	1%	1%	-
B. Type of travel party				
Alone	4%	5%	3%	15%
Couple	34%	59%	53%	51%
With children <12	13%	5%	7%	8%
With children >12	1%	6%	3%	7%
Friends	23%	11%	19%	24%
Bus Associates	9%	11%	7%	4%

Table 2 lists age and type of travel party. A Chi-square analysis indicated that there was a significant difference between the three Asian visitor groups in terms of age (Chi-square = 54.1, $p < 0.001$). Specifically the Chinese visitors were more evenly spread across all age ranges and were more likely than the other groups to be in the 41-50 year age group. Japanese visitors were younger overall than the other two Asian groups. A comparison with the Other International visitors showed that there were no consistent patterns of differences with variation across all the groups.

A similar conclusion also applied to the type of travel party. In this section of Table 2 Japanese and Korean visitors were most like the Other International visitors with the Chinese group being more likely to be with friends and family than any of the other groups.

Table 3: Experience with the destination.

Variable	Chinese	Japanese	Korean	Other International
Previous visits to the region				
None	68%	88%	91%	89%
1 or more visits	34%	12%	9%	11%
Visits to other coral reefs	58%	87%	38%	41%
Length of stay				
1/2 days	-	4%	-	3%
3-6 days	63%	51%	84%	28%
7-10 days	30%	34%	11%	23%
>10 days	7%	11%	5%	46%

Table 3 provides the distributions of answers to three questions related to experience with the Great Barrier Reef region in particular and with coral reefs in general. Again there were some significant differences between the groups with Chinese visitors much more likely than all other visitors to have visited the region before (Chi-square=355.8, p <0.001). Japanese visitors were significantly more likely to have visited other coral reefs (most probably in Hawaii, Guam, Indonesia, or Western Australia) (chi-square = 96.4, p<0.001). There was also a significant difference between the Asian visitors in terms of length of stay in the region (Chi-square= 162.3, p<0.001), with Korean visitors having the shortest stays. In this instance all three Asian groups had shorter stays than Other International visitors.

Table 4: Transport Use

Variable	Chinese	Japanese	Korean	Other International
Transport to the region				
Rental car	2%	1%	1%	10%
Coach/Bus	15%	3%	6%	17%
Plane	79%	94%	92%	34%
Transport within the region				
Private car	-	8%	3%	9%
Rental car	7%	5%	5%	11%
Campervan	4%	8%	2%	1%
Coach/Bus	85%	65%	76%	54%
Plane	4%	11%	11%	8%

Table 4 contains information about transport use, both to and within the GBR region. For all three Asian groups the main form of transport to the region was a plane and there was a major contrast between the three Asian groups and Other International visitors. In addition to rental cars, coaches and planes, Other International visitors used private vehicles, boats and rented campervans to travel to and within the region. None of these options were used by the Asian respondents. Within the three Asian groups there was, however, a significant difference with Chinese visitors more likely to use coaches to travel both to (chi-square= 42.3, $p<0.001$) and within the region (chi-square=61.3, $p<0.001$).

Table 5: Travel patterns in destination region.

Variable	Chinese	Japanese	Korean	Other International
Places they have spent at least one night (Plan to spend 1 night)				
Just arrived	12%	2%	2%	Not applicable
Port Douglas	1% (-)	1% (-)	- (-)	17% (4%)
Green island	- (1%)	6% (5%)	1% (2%)	2% (1%)
Cairns	85% (81%)	85% (83%)	94% (81%)	60% (9%)
Mission beach	- (2%)	- (-)	1% (1%)	16% (4%)
Dunk Island	- (-)	- (-)	1% (1%)	5% (1%)
Townsville/ Magnetic island	- (1%)	6% (-)	1% (1%)	35% (5.1%)

Table 6: Information sources.

Variable	Chinese	Japanese	Korean	Other International
Information				
No information	2%	4%	12%	2%
Friends/family	37%	34%	46%	48%
Travel agent	79%	75%	76%	22%
Newspaper/ Magazine	36%	31%	45%	17%
Accommodation	14%	34%	3%	12%
Automobile assoc.	1%	1%	23%	3%
Brochures outside region	4%	30%	1%	28%
Brochures inside region	3%	25%	8%	36%

Tables 5 and 6 provide information indicating the distribution of travel throughout the region under study and the major sources of information about the region. In each of these questions multiple responses were allowed and so no tests of statistical significance are possible. There were, however, some clear trends in the tables. With respect to travel patterns in the destination region, all three Asian groups centred their travel on Cairns, the main centre in the region. Other International visitors spread their travel much more widely throughout the region. In the case of information sources, all three groups of Asian visitors shared a level of use of travel agents and newspapers and magazines for information which was much higher than that of the Other International visitors. Apart from that there were few other clear patterns. Japanese visitors had the highest use of accommodation for information, both Japanese and Other International visitors had relatively high use of brochures picked up within the region, and Korean visitors made much higher use of automobile associations than any other group.

Table 7: Great Barrier Reef Experience.

Variable	Chinese	Japanese	Korean	Other International
Have visited GBR before this day trip	20%	33%	3%	39%
Planning to visit GBR again on this stay in region	25%	16%	4%	23%
If yes, what kind of trip?				
Large boat (>100 people)	62%	47%	Insufficient numbers for the analysis	28%
Medium boat (15-100 people)	35%	44%		40%
Small boat (<15 people)	3%	9%		32%

Table 7 contains the answers to questions specifically concerned with travel to, and experience of, the Great Barrier Reef. In this table we can see that Korean visitors were the least likely to have been to the GBR before on this trip and the least likely to be planning another visit during this trip to the region. When looking at the type of future GBR trip planned we can see that for Chinese visitors big boats were dominant, while Japanese visitors were evenly spread across big and medium boats, and Other International visitors were most interested in medium and small boats.

Table 8: Satisfaction with Great Barrier Reef Experiences.

Variable	Chinese	Japanese	Korean	Other International
Mean satisfaction score (standard deviation)	7.5 (1.9)	7.1 (1.7)	7.1 (1.7)	8.7 (1.5)
Do they intend to visit GBR on a future trip to the region				
No				
Yes	17%	5%	13%	20%
Don't know	35%	23%	62%	65%
	48%	72%	26%	15%
Would recommend GBR experience to friends/family?				
No	1%	4%	4%	2%
Don't know	16%	7%	14%	2%
Probably	55%	44%	49%	15%
Definitely	28%	45%	33%	81%

Finally Table 8 contains information assessing satisfaction with GBR experiences. The first component in the table is overall satisfaction with their reef experience and there were no major or significant differences between the three Asian groups. It is clear, however, that all three Asian groups were substantially less satisfied with their experiences than the Other International visitors. This was consistent with other information in this table. Specifically, Other International visitors were more likely to say that they will definitely recommend a GBR trip to their friends and family and to say that they will return to the GBR on a future trip to this region. Within the Asian groups the Japanese visitors were both the most likely to say that they would return to the GBR on a future trip to the region and that they would definitely recommend the experience to friends and family

CONCLUSIONS

There were only two sets of consistent differences between the Asian and Other International visitors. The first set of differences were related to the fact that all three Asian groups were most likely to be travelling as part of a package tour and that Other International visitors were most likely to be independent travellers. This high use of package tours is consistent with shorter stays in the region, greater use of planes and coaches for transport, greater use of travel agents for information, and more limited travel patterns in the region.

The other main difference was in satisfaction with GBR experiences. In this case Asian visitors were less satisfied than Other International visitors. It is likely that this reflects a lack of information about the reef provided in appropriate languages. Many of the big reef operators provide safety and operational messages in multiple languages, but typically educational information is available only in English. It may also be that the restricted range of reef trips currently available to package tours limits the opportunities for these visitors to match their experience with their expectations or motivations.

For most variables examined there were significant and substantial differences between the three Asian groups. Chinese visitors were more likely to be travelling with children, to have visited the region before, to travel by coach and to visit the GBR more than once on this trip to the region. Japanese visitors were the least likely to be part of an all inclusive package, to have visited other coral reefs, to have already been to the GBR trip during their present trip to use brochures and accommodation for information, and to be younger than 30 years. Korean visitors had the shortest stays, and the least experience of the region, the GBR and other coral reefs.

Both these summaries would suggest that it is unwise to treat all Asian visitors as a homogeneous groups and that different products and education programs need to be designed for each group. For Chinese visitors, for example, the inclusion of activities for children in educational programs should be considered. Educational programs for all three groups should recognise the importance of travel agents and tour guides and consider providing specific training or information to these groups. Educational programs for Korean visitors need to be aware of their lack of experience with coral reefs in general and the GBR in particular.

Finally we can look at changing patterns of experience and travel. Historically the early wave of Japanese visitors to the GBR were similar in profile to the current Korean visitors - they had more limited experience, they were older and they were most likely to be on all inclusive package tours. Over time, however, this group has diversified with fewer restrictions and greater experience. It is likely, therefore, that in the future a more diversified range of reef operations will find themselves having to deal with visitors from a variety of cultural backgrounds.

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SOCIAL SCIENCE RESEARCH NEEDS FOR SUSTAINABLE COASTAL AND MARINE TOURISM

Gianna Moscardo and Edward Kim

CRC Reef Research Centre
James Cook University
Townsville QLD Australia

ABSTRACT

Sustainable tourism can be characterized as tourism which is concerned with quality, balance and continuity. Sustainable tourism provides quality experiences for visitors, while maintaining the quality of the visited environment and improving the quality of life of the host community. To achieve these goals managers, both private and public, must make decisions based on quality information and reliable evidence. The aim of the CRC Reef Research Center team is to provide quality social science to support the development and management of sustainable coastal and marine tourism. This paper will define sustainable coastal and marine tourism and provide an overview of the different types of knowledge and information that are required to achieve a sustainable tourism industry. In particular the paper will examine the types of social science research that are necessary to inform management decisions on the provision of access, the regulation of activities and the allocation of facilities.

INTRODUCTION

Coastal and marine environments are attractive places for tourism and recreation. The history of tourism development is dominated by the rapid and massive growth of tourism to such places as the Mediterranean, the Caribbean, Hawaii, the Californian coast, Florida, Bali and Australia's Great Barrier Reef and Gold Coast. The seasonal migration of people from inland to coastal regions and from colder climates to warm tropical coasts is a marked pattern of both international and domestic tourism in almost all regions of the world. Islands and beaches offers milder climates, pleasant scenery, and ample opportunities to engage in a range of different pursuits. Tourism has become a major marine industry in many places around the world and is often the major economic activity for coastal communities.

Tourism has, however, the potential to be a very damaging human activity in these coastal and marine settings. The building of marinas, the reclamation of foreshores, the creation of artificial beaches and the destruction of mangroves are just some of the problems that have been associated with the building of the infrastructure to support tourism. Damage from cruise ship and tourist boat anchors, depletion of fish stocks to supply tourist restaurants, pollution of the water and damage to coral reefs from snorkeling, reef walking tours and divers have also been documented. The management of tourism and tourists is a major issue in many protected marine environments (Kenchington, 1993).

It is not surprising to find that in the last few years the tourism literature has been focussed on discussions of how to make tourism a more sustainable activity (Moscardo and Pearce, 1997). At the same time there has been a growing concern in the protected area management literature that traditional management models do not deal with the role and activities of humans in heritage and conservation environments (Hall and MacArthur, 1993, Machlis, 1996). This paper will describe one program of research being conducted in Australia concentrating on tourism to the Great Barrier Reef World Heritage Area. This research program seeks to address the related problems of making marine tourism more sustainable, and assisting managers to better deal with tourism as a major economic use of this protected marine environment. The core argument of this paper is that both these problems require systematic, reliable and relevant social science research into the patterns of tourism and the factors which shape and influence these patterns. Marine environment managers need:-

. to have a sound understanding of tourism as a system,
. to pursue regional strategic planning based on reliable and relevant information, and
. to make decisions on the basis of evidence rather than myths or stereotypes.

Understanding and Planning for Tourism

Currently in the field of tourism two concepts are seen as essential for the successful management of tourism. They are ecologically sustainable tourism and regional strategic planning. These two concepts are interrelated, focused on quality and both are critical to the successful management of protected areas. In Australia we have had the benefit of a federal government sponsored process of examining what ecologically sustainable development means for tourism (ESD Working Group, 1991). In this process ecologically sustainable tourism must:

improve material and non material well being of communities,
preserve intergenerational and intragenerational equity,
protect biological diversity and maintain ecological systems, and
ensure the cultural integrity and social cohesion of communities.

This definition thus includes a consideration of the economic viability and returns of tourism activities, as well as the social and cultural aspects and impacts of tourism. It is important to note this point as much of the discussion of ESD has been focussed on the biophysical components only. Table 1 provides a summary of the characteristics of ecologically sustainable tourism (EST).

To achieve such a tourism industry as described above requires regional strategic planning. What then are the core elements of strategic planning in tourism? Figure 1 summarizes these core elements or stages. The stages of most direct relevance to the present discussion are those of research and evaluation. These are the elements most often missing from the process of planning and management of heritage resources. Many authors have suggested that there has been too much emphasis, often as a result of political pressure, on development or implementation rather than research and evaluation (Butler and Waldbrook, 1991).

Table 1: Characteristics of Ecologically Sustainable Tourism.

Tourism which is concerned with the quality of experiences.

Tourism which has social equity and community involvement.

Tourism which operates within the limits of the resource - this includes minimisation of impacts and use of energy and the use of effective waste management and recycling techniques.

Tourism which maintains the full range of recreational, educational and cultural opportunities within and across generations.

Tourism which is based upon activities or designs which reflect the character of a region and which allows the guest to gain an understanding of the region visited and which encourages guests to be concerned about, and protective of, the host community and environment.

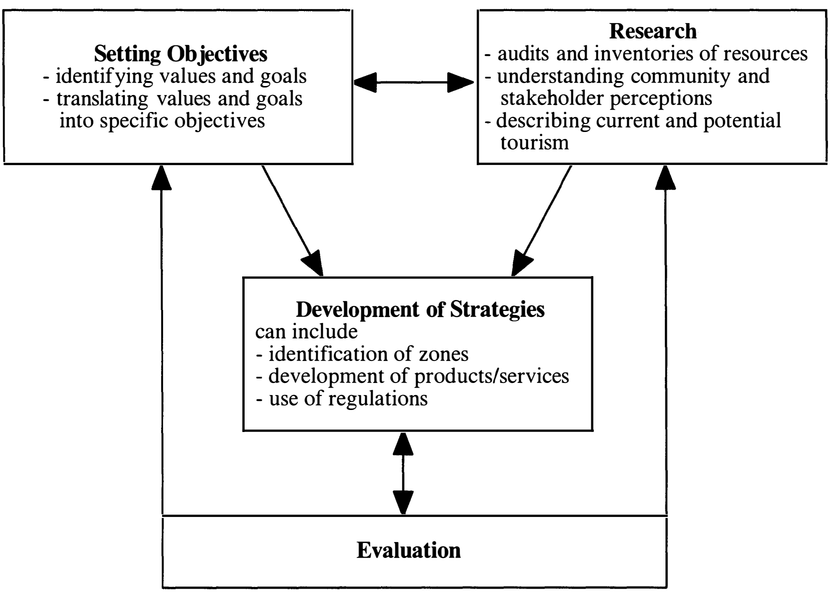

Figure 1: Core elements or processes in strategic tourism planning

There are three main categories included in the Research component as presented in Figure 1. As would be expected each of these is further broken down into more specific categories. Table 2 provides summaries of these more specific categories. The table includes a summary based on a review of several planning models all of which take a spatial or geographic perspective (see Gunn, 1994 for further information on these models).

Table 2: Summary of Research Needs for Tourism Strategic Planning.
An understanding of natural resources (includes water, vegetation, wildlife, climate, topography, land use) and assessments of carrying capacity.
Descriptions of existing tourism infrastructure and resources (includes transport, accommodation, information services and human resources).
Descriptions of tourists (including numbers, patterns of movement, use of tourism infrastructure, expectations, desired activities and evaluations).
Assessment of community support for, and perceptions of, tourism.
Assessment of government support and existing policies.

Constraints on the Use of Social Science Research.

Despite the existence of a large literature on strategic planning for tourism and on tourism management, it is often the case that management decisions are made without information on tourism and tourists. There are several reasons for this lack of use of social science methods and models in the management of tourism. These include:-

1. a lack of interest in applying social science research methods and models to tourism because tourism is seen as a frivolous and therefore inappropriate area of study for social scientists.

2. pressure to resolve problems in the short term and perceptions that the time required to collect relevant data is too long.

3. a dominance of the physical sciences in the education and experience of managers in the natural resource area.

It is this third feature that is of particular importance. Clearly unfamiliarity with research approaches and theories in social science disciplines limits the ability of managers to use and evaluate this kind of information. At a more fundamental level, however, unfamiliarity with scientific approaches to understanding human behavior can result in the use of various stereotypes and other shortcuts in the decision making process. There is a substantial body of research evidence demonstrating this pattern of thinking in which decisions are based on popular but inaccurate images and beliefs (Langer, 1989).

There exists a growing area of research which examines the images and beliefs that people, especially managers, hold about tourism and tourists (see Pearce, Moscardo and Ross, 1996 for a review of this research). A number of different stereotypes or myths exist and each can be related back to a general human thinking tendency identified in psychology. One of the most common tendencies in human thinking is to categorise people into groups. The most basic of these category systems is to establish an ingroup, which is people like us, and an outgroup, which is people not like us. In the case of tourism it is very common to identify tourists as an outgroup and to exaggerate how different they are to us. Tourists are often considered to be a single homogeneous mass group. Once we have developed categories we usually build a stereotype which describes the essential features of a typical example of that category. Research evidence shows that a typical tourist is seen as being an international visitors usually travelling on a package tour and basically concerned with relaxation. Basically we exaggerate how similar tourists are to each other and how different they are to us and we tend to think of only one sector of tourism when we use stereotypes to make judgements (Pearce, Moscardo and Ross, 1996). Unfortunately it is very rare that these stereotypes are accurate. One of the goals of tourism researchers in the CRC Reef Research Center is to challenge these stereotypes and to demonstrate the value of collecting systematic, reliable information on tourists.

The CRC Reef Research Center

The CRC Reef Research Center is a cooperative venture involving:-

1. academic researchers, from James Cook University,
2. government researchers, from the Australian Institute of Marine Science,
3. government agencies responsible for managing the Great Barrier Reef, especially the Great Barrier Reef Marine Park Authority and the Fisheries section of the Department of Primary Industries, and
4. industry partners, in particular the Association of Marine Park Tour Operators.

The overall objective of the center is to undertake an integrated program of applied research and development, training and extension aimed at enhancing the viability of, and expanding sustainable Reef-based industries and economic activity, with particular emphasis on tourism, and providing an improved scientific base for Reef management and regulatory decision making.

This objective specifically recognizes the importance of tourism to the communities who live along the coast adjacent to the Great Barrier Reef. Along with the outback and the rainforest, the Great Barrier Reef is a major icon used in Australia's tourist promotion. In 1982 the introduction of large, high speed catamarans changed the nature of reef tourism in this region dramatically. Prior to 1982 very few islands and reefs were easily accessible for day trips. These new boats offered much easier access to the reef for day trips. Growth in reef tourism in the following years has been fast with annual growth rates of approximately 30 percent for the northern access points. The number of commercial reef tour operators increased tenfold in the decade 1982 to 1992, with 35 times as many visitors going to 4 times as many sites. This growth has, until recently, not been associated with much diversity of operations. Rather the most common pattern has been a replication of a small number of particular types of operation. The most dominant, in terms of promotion and numbers of visitors, has been the large catamaran day trip to a pontoon moored at a reef. In recent years there has been, however, substantial growth in both the smaller day trips and dive trips. Overall it has been estimated that reef tourism contributes more than $A 750 million each year to the coastal economies (Kenchington, 1993).

The CRC Reef Research Center has three major research programs. One program is concerned with studies into the region's environmental status, (this program is mainly by scientists in the disciplines of oceanography, geology and ecology). There is an engineering program and the third program examines the impacts of human activities on the Great Barrier Reef. This third program is dominated by studies into the impacts and patterns of tourism on the reef and studies of recreational and commercial fishing practice. Researchers from the

Tourism Program in the James Cook University School of Business are responsible for examining the patterns of tourism on the Great Barrier Reef.
More specifically the research seeks to:-

- determine the scale, type and intensity of tourist use,
- determine characteristics of tourists,
- determine the nature of the tourist experience, and
- assess images of the Great Barrier Reef.

According to Machlis (1996) there are four types of useable knowledge. They are:-

1. **Information** - description of the situation, or answers to the question what is going on.
2. **Insights** - analyses of the key factors influencing the situation, or answers to the question - why is the situation as it is?
3. **Predictions** - developing models and assessing future scenarios, or answers to the question what might happen?
4. **Solutions** - assessments of new management strategies or actions, or answers to the question of what will happen if we change our management or introduce a new element?

The main focus of the CRC Reef Research Center has been on the Description and Insights levels with the longer term goals of developing appropriate bases for Predictions and Solutions. To answer these questions the research team has been building a web of tourist knowledge based on two main sources of data. The first is existing data collected by the Australian government on international and domestic visitors to Australia and survey data collected in a range of countries by the US and Canadian governments. The second is original data collected by the researchers in a variety of locations along the coastal region adjacent to the Great Barrier Reef and on various commercial tourist boats. This latter data set now contains nearly 7000 surveys completed in four languages.

These original surveys include questions on; place of residence, length of stay in the region, transport to and within the region, patterns of travel in the region, patterns of Great Barrier Reef travel, specific motivations for visiting the Great Barrier Reef, activity participation, previous reef and regional experiences, intended future travel to the region and the reef, best features and suggested improvements to the reef experience, demographics such as age, and type of travel party, and satisfaction with reef experiences.

SOME EXAMPLES OF THE RESEARCH AND ITS POTENTIAL MARINE MANAGEMENT IMPLICATIONS

Describing Patterns of Great Barrier Reef Travel.

Prior to the development of the CRC Reef Research Center tourism database managers knew about the overall number and spatial distribution of visits to the GBR on commercial tour operations. They did not, however, know the level or patterns of repeat reef visitation and whether or not visitors using different types of reef operations constituted separate groups or overlapped. An investigation of this issue found that 19% of visitors to the coastal regions adjacent to the GBR did not go on a commercial reef tour, 41% went once only and 40% had either been more than once, or had been once and intended to again. These patterns of visitation were strongly associated with the types of reef tourism operations used. Day trips with large catamarans were the most popular option for once only visitors, while multiple visit tourists were spread across a range of different operations. Table 3 summarizes the key results of these repeat visit analyses.

Table 3: Types of Tourist Operations and Points of Departure Chosen for Reef Trips.

Type of Operation	Visit Once Only	First Visit for Repeat Visitors	Second Visit for Repeat Visitors
Large day trip	49%	32%	27%
Smaller day trip	26%	10%	7%
Cruise (>1 night)	4%	5%	3%
Dive trip (>1 night)	2%	12%	5%
Dive trip (day trip)	3%	13%	9%
Charter Fishing	-	2%	3%
Island day trip	16%	15%	22%
Other	-	13%	24%

Of particular interest in this table is the difference between first and second trips for those who go more than once to the GBR. Visitors clearly seek variety in their reef tourism experiences with 72% choosing a different type of operation for the second trip. This was particularly the case for large day trip operations. The surveyed tourists also chose variety in their departure points with 53% choosing a different coastal location for their second trip. (See Moscardo and Woods, 1998 for further details of this study).

Several important management implications can be drawn from the results of these analyses. The most important is that of growth and change in demand for reef operations into the future. Clearly there will be continued demand for large reef operations if overall tourism to the adjacent coastal regions continues to grow. As the region matures as a destination, however, and attracts higher proportions of repeat visitors, the present study results suggest greater demand for smaller, more specialized operations at a greater variety of locations. Demand is likely to both support existing high use nodes and spread use to other areas. Given that other results from this study demonstrated that those tourists who sought the smaller operations were more active and much more likely to get into the water and so closer to the reef, this increased demand will result in greater pressure on a broader range of reef settings.

Investigating Assumptions About, and Stereotypes of, Ecotourists

One area of central importance to managers of protected areas is that of limiting or eliminating the negative impacts of human use. In the introduction we listed several negative impacts that tourists can have in coastal and marine environments including damage to coral from anchors, snorkeling and diving, and problems with water quality from tourism waste. One option for managing the environmental impacts of tourism that has been given much attention in recent times is the proposal that mass tourism can be replaced with smaller scale alternative types of tourism usually referred to as ecotourism. This argument is based on two assumptions. The first is that mass tourism must have greater environmental impacts than ecotourism because it involves many more people. The second assumption is that ecotourism is a specialist type of activity that will attract higher yield visitors. That is, ecotourists are prepared to pay more for their tourism experiences and so larger numbers of mass tourists can be replaced by smaller numbers of ecotourists with little difference in the economic returns to the tour operators. This conclusion also assumes that there are sufficient numbers of these big spending ecotourists to sustain this change.

This proposal of creating a more sustainable tourism industry by replacing mass tourism with small scale specialist ecotourism has come under increasing attack. Firstly, many studies of impacts have demonstrated that negative environmental impacts are rarely the result of simply large numbers of visitors. Indeed it has often been demonstrated that some activities can result in a great deal of damage even if pursued by only a small number of visitors (Moscardo, 1997). Secondly, it has been argued that there is little evidence that ecotourists are willing to pay more for their tourism experiences. There is also little evidence that even if they are more willing to pay, that there exists sufficient demand for these specialist ecotourism experiences. Information on visitor demand for particular experiences and profiles of visitors seeking different types of experience is one obvious way to examine this latter argument.

The CRC Reef Research tourism team has been investigating demand for GBR ecotourism and the profiles of these reef ecotourists. The researchers searched international visitor survey data sets collected in Japan, Australia, Taiwan, Germany, the Netherlands and the United Kingdom. Ecotourists were identified using visitors' ratings of the importance of various tourism experiences such as seeking wilderness and undisturbed nature, chances to see wildlife and birds not normally seen at home and visits to appreciate natural ecological sites. The largest proportions of ecotourists were found in the German (46%) and Dutch (28%) samples, with 19% of the UK, 16% of the Australian, 15% of the Japanese and 6% of the Taiwanese samples identified as ecotourists. Given the dominance of the Japanese and the rising importance of Chinese visitors to the GBR regions these results suggest that there is not currently strong demand for reef ecotourism experiences. Further examinations of the profiles of the German and Dutch ecotourists suggested that these two groups were likely to be budget conscious travelers rather than big spenders. A comparison of ecotourists and the rest of the Australian, Japanese and Taiwanese samples failed to find any significant differences in terms of income, amount spent on travel, or frequency of travel. In short little evidence could be found to support the assumption that ecotourists are necessarily high yield tourists or that there was strong demand for these types of experiences (further information some of this research is available in Woods and Moscardo, 1998)

SUMMARY

Managers of many coastal and marine areas, especially protected, conservation or heritage areas, have three main tasks. They have to manage the structure of the area. That is, ensure the preservation of viable examples of the ecosystems under protection. They also have to maintain those processes necessary to sustain these ecosystems, and they have to manage amenity. In most coastal and marine environments managers have to provide options for, and control human use of the area (Kenchington, 1993). It is this last task and its interaction with the other two that was the central concern of this paper. In particular the challenge for coastal and marine area managers is to balance actions which minimize the negative impacts of human activities with the economic and socio-cultural needs of the humans who use these areas in various ways.

In many coastal and marine areas one of the important economic and social uses of the environment is tourism. Tourism does, however, have the potential to cause damage to those structures and processes that managers must maintain. A number of management options to limit these negative tourism impacts exist and these include limiting the numbers of visitors allowed to pursue various activities, regulating to control aspects of the activities, providing education about the activities and not allowing the activities.

Choosing between these options depends not only upon the nature of the actual impacts themselves but also upon the demand for, and nature of the tourists engaging in these activities. Social science research can provide valuable information on the types of activities and experiences sought by coastal and marine tourists. Knowledge of the demand for certain activities and experiences provides information on the demand for infrastructure and potential points of impact. If most visitors seek only a passive experience with little direct or actual contact with marine environments such as coral reefs then the major source of impacts will be the infrastructure developed for these visitors. If, however, a substantial number of visitors seek more contact through activities such as diving and fishing then there may also be demand for access to the environment and potential for a wider range of impacts.

This paper has reviewed the principles of sustainable tourism and argued for greater and more systematic analysis and use of information about tourists in the management of marine and coastal environments. The paper also reported on new initiatives in this area being sponsored by the CRC Reef Research Center and provided some examples of the potential management value of social science research results. These examples represent just a selection of the actual analyses that have been conducted. More details of the research are available on the research teams website at http://www.jcu.edu.au/dept/ARRVR.

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THE USE OF FINE GRAINED MANGANESE AS AN INDUSTRIAL FILLER

John Wiltshire and Tom Loudat

Hawaii Undersea Research Laboratory
University of Hawaii, Honolulu, Hawaii, USA
johnw@soest.hawaii.edu

ABSTRACT

Manganese nodules and crusts represent an ocean mineral resource which will likely be developed during the course of the twenty-first century. Recent environmental work on manganese crusts has shown that 75% of the environmental problem associated with marine ferromanganese operations will be with the processing phase of the operation, particularly the disposal of the waste material, the tailings. Traditionally, mine tailings are dumped in a tailings pond and left. Current work with manganese tailings has shown them to be a resource of considerable value in their own right. Tailings have applications in a range of building materials. This paper will review the ways tailings are disposed and a potential alternate use of these tailings. The tailings serve as an excellent filler for certain classes of resin cast solid surfaces, tiles, asphalt, rubber, plastics and composites. The grain size range of the tailings may have to be narrowed for optimal filler performance. The manganese appears to have some anti-biofouling capabilities. The effect of using mineral tailings for secondary applications enhances the profitability of a marine mining operation by a small but important margin.

INTRODUCTION

Manganese nodules and crusts represent resources which will likely be developed during the course of the twenty-first century. Mining of manganese nodules in the Pacific is currently planned by at least two government mining groups. Mining of manganese crusts is under active contemplation in the 200 mile exclusive economic zone around Johnston Island in the mid Pacific by several multinational corporations. The twenty-first century will also almost certainly be marked by heightened environmental consciousness. At a time when increasingly greater numbers of diseases are linked to environmental causes, and environmental litigation is at an all time high, it is difficult to imagine that an entire new class of mining operation: deepsea mining, would be able to come into production without the tightest of controls. Recent environmental work on manganese crusts (DOI, 1990) has shown that 75% of the environmental problem would be associated with the processing phase of the operation. Most of this has to do with the disposal of the waste material, the tailings.

Most terrestrial mines do the primary ore concentration on site as it is expensive to ship waste rock. Almost every mine therefore has a tailings disposal pond. Simply dumping the tailings at the mine site is the traditional and simplest way of tailings disposal. In recent years, elaborate forms of pond liners and reclamation practices have been developed. While these are laudable in comparison with earlier practices, in actual fact most tailings ponds only delay environmental problems to a later time when the liners break and the material leaches into the ground water. Permanent solutions must involve some form of returning the tailings back into the cycle of the environment. This paper is predicated on the assumption that inadequate disposal practices of the past will not be tolerated for new marine mining operations in the future.

Another factor to be taken into account is that mining is a changing industry. This change is being driven by advances in computer power, communications, robotics, fiber optics, and sensors. Mining in the twenty-first century will be highly specific and high tech. Great efforts will be made to mine only valuable ore and minimize the amount of waste material taken. This will be done by small robotic miners using small specialized cutter heads or in situ leaching to take ore only and not gangue. The mine of the future will be more efficient than the present mine, meaning the gangue to ore ratio will be very low. The amount of tailings will decline with time. As processing becomes more efficient the tailings left will decline as well. Tailings are now being taken into account in the design of processes to insure that the waste at the end of the mining cycle is manageable.

The ideal solution to mine waste disposal is where the tailings can be sold as a byproduct to a third party and provide income to the mine as well as eliminating a disposal problem. Surprisingly, very little effort has been spent in this direction by the mining industry. There are two basic reasons for this. First, compared to selling ore, selling tailings is difficult and relatively unprofitable. It would be most unusual for one tailings customer to be able to take even a significant fraction, let alone most of a mine's tailings. Every customer has different requirements for the tailings. Most requirements involve some processing of the tailings, typical would be drying, sizing, bagging or removing some mineral fraction. This sort of thing is costly, particularly in small quantities. Second, most mines are able to meet current regulations for tailings disposal simply by dumping the tailings in a tailings pond and later either planting over this pond or just simply leaving it when the mine is finally abandoned. However, as the regulatory noose tightens on the neck of the mining industry, alternatives to current practices will be investigated more assiduously.

This paper will focus on recent alternatives developed for marine minerals tailings management rather than traditional disposal approaches. The literature on the engineering principles, successes and failures of current tailings management practices is very complete (Aplin and Argall, 1973: Sengupta, 1993). The tailings referred to in this paper include those of manganese nodules and crusts as well as analogous terrestrial manganese tailings.

Most manganese from terrestrial deposits is used in steel making. Steel makers prefer lump manganese and generally cannot readily use the fine grained material. The beneficiation processes involved in upgrading the manganese lump produces waste fine grained tailings of at least two sizes. These tailings are virtually identical to those which would be produced by a marine operation mining manganese nodules or manganese crusts (Troy and Wiltshire, 1998). The total estimated expense of tailing's disposal for these operations can be up to $10 million/year. Land based manganese producers typically pay more than $1 million per year simply to maintain tailings dams.

TAILINGS DISPOSAL AND ITS PROBLEMS

Tailings ponds are the classical way of mine disposal. These large impounding structures consist of a dike , an inflow and a decant system. Usually the material discharged into the ponds is waste from the mine concentrator only. Sometimes the discharge includes general industrial waste as well as concentrator effluent. The discharge methods include peripheral discharge or a point discharge system into the ponds. In the point system the point end of the discharge pipe is often moved as the tailings pond is systematically filled.

Tailings ponds are constructed in one of two ways. Either the containment walls are constructed with the mill tailings themselves or with materials from nearby quarries. Using the mill tailings is considerably cheaper. A starter dam of quarried material must first be built in either case. If the tailings themselves can be used for the dikes, the initial dam is followed by gradual buildup of the coarser material from the mill tailings. The disadvantage in using the tailings is in controlling the grain size and compaction characteristics to prevent dam failure or seepage.

The tailings from the mill are cycloned which separates some of the size fractions. The cyclone overflow might contain 10% fines whereas the underflow could contain as much as 70% sand. The fines are deposited behind the tailings dams while the sand could be deposited to form the dike. In the best engineering practice this sand fraction of the tailings is deposited between an upstream and downstream starter dike, forming the core of the final tailings dam. The sand is allowed to dewater for several days and then positioned in the tailings embankment using heavy earth moving equipment. A well designed dam also has a drainage system to remove seepage water from the tailings dam sand core. By contrast, dams built of excavated materials are either completely constructed at the beginning of the project or are partially constructed at the beginning and gradually added too as the project goes on, should a later need arise. Material can come from an independent excavation or could be overburden or waste rock from the mine. Clearly, if mine overburden can be used this is a considerable saving over a new excavation.

One of the major problems with tailings dams is seepage. Seepage both affects the local area by allowing contaminated water out of the dam and contributes to dam weakening and collapse. A wide range of methods are used to reduce seepage. These include the placement of impervious clay or soil layers in the core of the dike. Some ponds are lined with concrete, asphalt or grout. Membranes or layers of very fine tailings have also been used. While these methods can prevent seepage while the tailings pond is in operation, if properly emplaced, they tend to break down over time once the pond is abandoned.

Tailings are usually pumped into the tailings dam in a slurry. They thus contain a significant amount of effluent water. As the more solid part of the waste sinks in the ponds the effluent must be removed. The liquid to be decanted is much less than the total liquid input to the tailings ponds as liquid is lost to seepage and evaporation as well as entrapped in the tailings. Depending on its chemical constituents, this liquid may be recycled back to the plant as process make up water. If it is quite clean it may be discharged into a natural drainage, typically a stream, river or lake or it may be used in agricultural irrigation in the best designed systems. In the more likely case that it is contaminated, it will go to an evaporation pond or special treatment pond.

The effluent from a tailings pond is collected in one of three ways. The best and probably most common way is to build a decant system into the tailings pond. Such a system is made with a series of towers in the tailings pond with attached piping running underneath the pond to a pump station and then to discharge or recycle to the plant. As the capacity of the tailings pond is used and the tailings dam built higher, the height of the decant towers is also increased by adding sections of pipe or precast concrete rings. The towers are designed so that sections can be added for the entire life of the pond. The sections are typically less than a foot in height and carefully adjusted to the rising water level in the ponds. Drainage through the decant system is only through the top and is protected from clogging by screens. This tower decant system is the best for the drainage of tailings ponds as it is built in and when the pond is finally abandoned the tailings drainage system will still be functional to handle rain overflow and final pond drainage.

Less satisfactory alternatives involve the use of pumps or siphons place over the tailings dams. In that these methods do not require the infrastructure of towers or under pond piping they are cheaper. However, simply trying to pump or siphon a large pond from one or several points along the edge is subject to a host of problems including power outages, the need to continually reposition the intakes and drains, problems with heavy rains or freezing in winter and perhaps most severe the complete lack of a drainage system after mine abandonment.

Although tailings ponds are the principal method of tailings disposal and have been in use worldwide for many years, they have a history fraught with problems. Foremost are large areas of devastated land and polluted water from pond seepage and runoff. Slump collapse of the tailings dams during the active life of the mine or after its abandonment is unfortunately also relatively common. This is particular problem for high abandoned tailings dams (some of these dams can be 100 meters in height) in areas of heavy rainfall. While significant progress in tailings pond abandonment procedure has taken place including planting over dams, reducing slopes, grading and cementing (Aplin and Argll, 1973; Sengupta ,1993) the problem has as much been shifted into the future as solved. A far better solution would be utilization of the tailings.

THE FILLER MARKET

Ongoing research at the University of Hawaii is demonstrating that manganese tailings can, in fact, be used in a range of secondary industries. In particular, the project has had success looking at fine grained manganese tailings as an industrial filler. This would be for plastic, rubber, resin casting (solid surface or cultured marble), asphalt, brick, or paint fillers. Other work (Wiltshire, 1997 and 1999; Wiltshire and Loudat, 1998; Osaki *et al.*,1987; El Swaify and Chromec, 1995) has shown that manganese tailings are useful in agricultural applications, concrete, ceramics and drilling mud. The work on industrial fillers will be highlighted in this paper.

The specific properties associated with these fillers are largely grain size related. Typically, the best filler material has a narrow size range of not more than 0.1-20 microns. For highly specific applications this size range could be even narrower. In the case of rubber, a range of less than 5 microns would be required for a high grade product. Fillers come in a variety of types depending on the need. Most of the filler market is dominated by half a dozen mineral products. These are: silicas and highly dispersed silicas, kaolin clay, calcium carbonate, alumina trihydrate, magnesium hydroxide and onyx. All of these fillers come in several size ranges and are classified by the median grain size. Typically the median grain size would be between 1 and 10 microns. Maximum size of the particles is also significant. Most filler specifications give the percentage of the filler which is greater than 325 mesh (45 microns).

Fillers command a price structure based on whether they are simply inert or impart beneficial properties to the resulting product. Within a given mineral product line, price is also related to grain size distribution and packaging. In general, the smaller the median size and narrower the size range, the higher the price. Packaging is typically in 50 lb bags packed on pallets, 2000 lb bags and bulk. The value of inert fillers is in the range of $.03/kg while active fillers can command values of $.25/kg or more.

One of the trends in the current filler market is to modify the surface layer of the filler for improved performance. Active organic molecules known as silanes are thinly coated onto the filler particle surfaces. Typically the silane coating would be 100 molecular layers or less in thickness. The silanes have an active end which binds the filler particle to the strands of the polymers in the carrier. The resulting engineered material has greatly enhanced performance. Typical results included increased strength, moldability and surface hardness as well as reduced porosity and susceptibility to staining, acid and alkali degradation. A number of plants operate worldwide specializing in modifying the surface layer of fillers. One such plant is operated by United Minerals in Arkansas. It has the ability to provide silane modification to manganese tailings for enhanced filler applications on a toll basis.

MANGANESE FILLER APPLICATIONS

The manganese tailings can be of several sizes, typically a sand size range and a silt-clay size range. The particles are angular, hard and represent a range of mineralogies. When dried and de-clumped (the material has a tendency to aggregate) the tailings are a fine grained, black, odorless powder. Tailings properties have been described at length in Haynes *et al.* (1985), Wiltshire and Loudat, (1998) and Troy and Wiltshire (1998). The experimentation done for this work used terrestrial manganese tailings from the Groote Eylandt manganese deposit in Northern Australia. No modification was done to these tailings. For a broad application commercial filler, the particle size range of the tailings would need to be narrowed, although the median grain size of about 3 microns is excellent for a large range of filler applications (see Tables 3 and 4). To narrow the grain size range, the upper size ranges above perhaps 20 microns would be removed by air classifiers. Surface modification with silanes is probably also desirable and cost effective. Four classes of applications were examined in detail. These are listed below with the general results:

a) Resin Casting-Solid Surface. A major use of fillers is in counter tops and fixtures. These are referred to as solid surface and cultured marble applications. The filler is mixed with specialty resins usually in proportions of about one third resin, two thirds filler. The resin-filler mix is activated by the addition of a catalyst and the mix is poured into a mold to cure as a casting. Sink and shower fixtures were professionally cast using manganese tailings by a small Hawaii synthetic marble producer. They were very attractive and considered commercially equivalent to white synthetic marble (only black or gray).

b) Tiles. Tailings tiles were also manufactured by casting mixtures of tailings and resin in glass molds. They were laid in a warehouse on the Island of Hawaii. They are attractive and can be easily installed with a little practice. The tiles were sent to the Ceramic Tile Institute of America for commercial testing. The manganese tiles tested within the range of certifiable floor tiles for some but not all of the required standard properties. The tests showed the tiles to have undesirably high thermal expansion and to have only 60% of the bonding strength to the floor required for certified tiles. Part of the problem here is that the bonding agent used in the test was designed for ceramic tile not resin cast tile. While attractive and testing in the general range of commercial products, it is clear that more work will have to be done before tailings could be made into tiles for wide commercial application.

c) Rubber. Fillers are also extensively used in the rubber industry. Most commonly the preferred filler is a clay. Commercial testing was done by two rubber corporations using the tailings as a filler. The tailings mix well in rubber mixes, show increased abrasion resistance and tear strength over standard fillers and had a high index of dispersion. However, the range of grain size of the tailings is too large for the rubber industry. In general, rubber applications require 100% of the filler grains to be less than 10 microns. In the case of the manganese tailings only 80% of grains are less than 10 microns. This is an easily resolvable problem, but one that would incur some sizing costs. Without this size correction the tailings performed poorly on rubber tests where the particle size distribution was a major factor. This was particularly true for overall strength and modulus of elongation.

d) Plastics and Composites. Several minerals, particularly calcium carbonate, are used as inert fillers with many different polymers to achieve plastics of a wide variety of characteristics. Normally carbon black is added to the plastic to get dark, gray or black colors for electronic housings, computers and automobile parts. Generally plastic properties are determined by the polymer and not the filler. Black plastics tend to fade rapidly under UV light. Plastics made with manganese tailings do not fade. This is very significant for external applications. Manganese tailings tested successfully in a range of plastics. However, as in the case of rubber, the tailings would be better if the fraction above 10 microns in size were removed. A few applications can tolerate grains size to 200 microns but this is a small portion of the plastic filler market. Composites are various combinations of polymers and fibers, typically the fibers being carbon fibers, glass fibers, or fiberglass mat. Composites are layered, often using other material as a core such as wood or styrofoam and covering it with layers of fiber running at an angle to each other for strength, resistance to cracking and flexibility. Fillers have a specialized role in composites to extend the resin and penetrate the fiber mesh giving enhanced properties while reducing cost. Silane coated fillers are especially applicable in the composite market.

EXPERIMENTAL OVERVIEW

The largest area of research focused on fillers for resin casting. Resin casting involves mixing dry tailings with an appropriate resin and catalyst, pouring the mixture in a mold, letting it harden and polishing the final product as necessary. The final product's size and shape are essentially only dependent on the mold. The major difference between resin casting and plastics and rubber is that the resin cast products are hard whereas the plastic and rubber products are flexible, simply as a result of using a different polymer. In general, the tolerances of mix chemistry and temperature are less stringent for resin cast applications than for thin plastics and rubber.

Resin cast products were investigated in three categories: 1) artifacts and decorative items, 2) tiles, bricks, blocks and structural items, 3) fixtures and solid surface items. While the basic casting process is the same for each of these categories, the requirements and nature of the value added are quite different. Initial experimentation was undertaken in conjunction with Naka's Marble, a very successful synthetic marble casting operation in Honolulu. They produce fixtures and counter tops (solid surface). Naka's normally uses ground limestone mixed with a Silmar Interplastic Corporation marble resin. For this project they used the same S-585 resin but with manganese tailings instead of calcium carbonate (ground limestone). The resulting casting were lustrous, attractive and met industry standards.

Silmar Interplastic tested the tailings with various of their resins. They found the tailings to mix well with the resin, gel and cure normally. The tailings required a highly promoted resin system (Silmar S-585) which is commonly used in solid surface applications (the class of resins is known as the BPO polymer system). While S-585 resin is not optimized to the tailings, it is certainly quite easy to work with. Silmar could relatively cheaply and easily make a custom resin optimized to the tailings if the need arose. Silmar told us verbally they felt the tailings were 'a nice little filler' and had a definite place in the market. Silmar experimented with mixtures of 50% resin and 50% tailings (a standard testing procedure using 1.25% catalyst). We found in our work that 60 % tailings to 40% resin gave good results and used less resin. The Silmar results are noted in Table 1.

Table 1: Curing Characteristics of Two Typical Resins
With and Without Manganese Tailings

Resin Type	Neat Resin gel time / time to peak / peak exotherm (min. / min. / degrees F)	Filler Matrix gel time / time to peak / peak exotherm (min. / min. / degrees F)
S-585	11.2 / 11.2 / 299	15.5 / 27.5 / 110
S-40	14.8 / 21.3 / 298	22.5 / 30.5 / 97

In contrast to fixtures, small decorative items, artifacts, for lack of a better term, are an even lower tech tailings application. There are no industry standards. The value of the piece is solely determined by appearance. Tailings are dried and declumped, mixed with resin and catalyst, stirred with an electric drill and stirrer, poured into a mold, shaken to release bubbles, let stand to harden (several hours), polished if needed and shipped. A series of Hawaiian artifacts have been made and positively commented on by industry evaluators.

The final area of cast product research was tiles, blocks and structural items. Several hundred tiles of different designs and collarations were manufactured, tested and laid in the warehouse on the island of Hawaii. The tiles were straightforward to make. They laid easily and provided a hard attractive floor covering. The tiles were sent to the Ceramic Tile Institute of America for testing. The test results were negative. The tiles did not meet construction industry standards in a number of areas. The greatest problems were a high coefficient of thermal expansion (ASTM test C372) and chemical etching by an alkali solution (ASTM test C650). Our research team concluded that even going to a higher grade, costly epoxy resin might not be able to greatly improve these two test results although it would allow us to meet the other standards. The inability to meet these standards restricts the use of resin cast tiles to indoor and wall applications. For this reason tiles, blocks and structural members are not a promising market for tailings utilization.

Two other areas related to resin casting are plastic and rubber fillers. Of these, rubber fillers are a potentially larger market given the black color of the tailings which is applicable to only select plastics. Extensive testing of the tailings was done by Akron Rubber Development Corporation and by Roppe Corporation. Both groups got similar results. These results are summarized in Table 2. The tailings mix well in rubber mixes, show increased abrasion resistance and tear strength over standard fillers and had a high index of dispersion. Unfortunately, the grain size of the tailings is large for rubber and plastic applications. Therefore on the series of tests which were dependent on particle size, that is, strength, modulus of elongation etc., the tailings performed more poorly. In extensive discussions, Akron Rubber Development Corporation felt that by reducing the particle size to the appropriate range (less than 10 microns) and having a narrower size distribution, the tailings would perform to commercial standards.

In order to be optimized for casting operations the grain size distribution of the tailings needs to be altered. A detailed profile of the current grain size distribution of dried declumped tailings was calculated by Micromeritics Corporation and is presented in Table 3. Generally, each application for resin cast products needs a different ideal size range. The Table 4 gives samples of the preferred size range for each of a range of sub-industries.

Table 2 : Tailings Performance as a Rubber Filler: Part A :Mixed with 50% Clay

Item	Control 220 phr clay	Tailings 50% mix	Comment (110 phr clay, 110 phr tailings)
particle size	4 to 5	5 -100	
Cured at 315 F	10	20	longer cure time may be due to pH of the material (5.5) alternative cure system may work better (TETD accelerator)
Specific Gravity	1.49	1.55	
Hardness, Shore A	84	80	
Modulus, 10% psi	255	177	particle size dependent, finer particles give reinforcement this may explain poor performance by tailings
Modulus, 100% psi	868	297	finer particles give better result
Tensile Strength, psi	1,108	625	finer particles give better result
Elongation at Break, %	173	120	
Tear Strength (die C), psi	130	160	better performance by tailings
abrasion	0.63	0.49	18 wheel, 500 gm wt. test, tailings were superior
deterioration			Zn and Mn ions are reported to accelerate rubber deterioration

Table 2 : Tailings Performance as a Rubber Filler: Part B 100% Tailings

Property	Hard Clay	Tailings	Comments
Specific Gravity	2.65	3.5	
Particle Size (microns)	1	5 - 100	
Maximum torque	50.25	22.72	ASTM D2084-93 (MH, Lbf inch)
Minimum torque	18.81	8.66	ASTM D2084-93 (ML , Lbf inch)
Scorch Time	5.58	11.08	(Ts 1, Mins.)
Cure Time	12.25	17.46	(Tc 50%, Mins.)
Cure Time	22.17	26.96	(Tc 90%, Mins.)
Cure Temp.	145	145	centigrade ASTM D3182(clay), ASTM D624-T (tailings)
Cure Time (mins.)	50	50	
Philips Dispersion	6	9	dispersion rating 0-10, 30x magnification, 0=poor, 10=excellent
Ultimate Elongation %	420	770	ASTM D 412-92 & D 2240-91, ASTM Die C dumbbells
100% Modulus	450	180	test as above 20 in/min crosshead speed
200% Modulus	720	260	
300% Modulus	970	330	
Tensile Strength	1300	570	
Shore A durometer (points)	66	56	
Tear Strength (psi)	363	202	ASTM Die C, 20in/min crosshead speed

note: tailings disperse very well but perform poorly on some of the other tests because of the large particle sizes and size range making many of these tests unreliable as they are designed for smaller particle sizes and size ranges.

Table 3 : Tailings Particle Size Distribution

Cumulative Mass Finer (Percent)	Mass Frequency (Percent)	High Diameter (microns)	Low Diameter (microns)	Average Diameter (microns)
100	0	307	307	307
98	2	307	34	101
96	2	34	23	28
94	2	23	19	21
90	4	19	15	17
85	5	15	12	13
80	5	12	9.1	10
70	10	9.1	5.6	7.1
60	10	5.6	3.3	4.3
50	10	3.3	2	2.6
40	10	2	1.3	1.6
30	10	1.3	0.7	0.9
25	5	0.7	0.5	0.6
20	5	0.5	0.4	0.4
15	5	0.4	0.3	0.3
10	5	0.3	0.2	0.2

Table 4 : Particle Size Preference for Various Filler Industries

Application	**Particle Size Range**
solid surface	5 - 10 microns
deburring chips	20 - 50 microns
rubber	< 10 microns, preferably <1 micron
cultured marble	200 microns (2 parts) + 10 microns (1 part)

Given the size of the filler market for resin casting, rubber and plastics, many fillers compete for market share. Some of the more common of these are: calcium carbonate, alumina trihydrate, titanium dioxide, calcium sulfate, and magnesium hydroxide. Several varieties of manganese fillers are also widely available including several grades of manganese dioxide, manganese carbonate and manganese chloride. The value of these fillers varies from a few cents to over a dollar /lb depending on grade, grain size, packaging, delivery charges and size of order. Dried manganese tailings would fall in the low end of this range. The exact value of the tailings will depend more on marketing, packaging and delivery than on the actual tailings properties.

Two properties of the tailings are significant in terms of value added beyond just a plain filler. The first of these is ability to take color. It was determined that mixes with 55% tailings, 35% resin and 10% coloring pigment can achieve a wide range of very attractive colors ranging from vibrant reds through greens and blues. The tailings take color pigments well and give a richness to the color. American Colors (a pigment powder supplier) was favorably impressed with the results obtained. Perhaps more important, we determined that these tailings based mixes do not easily lose color permanence under UV light. This is a tremendous problem for the construction industry and restricts the use of darker color resin cast products for exterior applications. UV resistance of resin cast tailings products showed samples exposed to QUV B (harsher than QUV A) in a cycle of UV exposure (4 hrs) then condensation (4 hrs) performed exceptionally well. The darker colors and the grays which had higher tailings contents than the lighter colors performed the best. Since there is still no definitive correlation of these UV results with real time, these results were confirmed with real time tests of the samples in the Hawaii sun. Resin cast tailings tiles received 4 months of intense "real time" exposure. There were no perceptible UV shifts.

CONCLUSION

In summary, resin cast applications for decorative purposes, artifacts, and fixtures show considerable promise. A small casting industry could be easily and relatively inexpensively be set up as a small business. Tailings as rubber and plastic fillers need additional modification to reduce particle size. Applications in tiles and resin cast structural members will be limited until ways can be found to meet ASTM standards. The worldwide market for manganese fillers could be on the order of one to two million tons a year. At a typical low end price this could generate revenues of $50 million/yr for a marine mining operation. The use of fine grained manganese tailings as fillers offers a major benefit to the future ocean minor not only for increasing sales revenues but also decreasing environmental liability.

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ANALYSIS OF UNSTEADY STATE SLURRY FLOW MECHANISM IN PIPE FOR AIR LIFTING SYSTEM

Chi Ho Yoon, In Kee Kim and Kwang Soo Kwon

Korea Institute of Geology, Mining and Materials(KIGAM)
Taejon, KOREA
ych@rock25t.kigam.re.kr

ABSTRACT

The characteristics of three phase flow of air-liquid-solid in an unsteady state in a lift pipe were analyzed. This modeling qualitatively predicted most of the instability problems in the operating system. The governing equations for this modeling were manually reformulated from the Navier-Stokes equation which is made of momentum, continuity and constitutive equations. This paper presents the flow behaviors of the three phases with air, sea water, and manganese nodules in the lift pipe which were quantitatively analyzed using numerical modeling for the above governing equations. These results can be used to successfully predict the flow characteristics and configurations for stabilized operation in lab and pilot scale tests for an air lifting system.

INTRODUCTION

The developed countries have shown interest in deep-sea minerals to secure mineral resources since the 1960's because of the depletion of land minerals. The important minerals obtained from the deep-sea bed are manganese nodules and manganese crust, which contain various useful mineral components. Various kinds of research were performed to prevent loss of investments. Air lifts such as used in mining systems were studied to increase mining efficiency. Air lifting system lifts the water by applying a density difference between water and the mixtures of water and air by injecting compressed air at the bottom of the lift pipe. When the velocity of the water in the lower part of the air injecting pipe is greater than the settling velocity of the manganese nodules, the three phase mixture of air, water and nodules flows upward. In order to understand this flow mechanism, one quick way is the analysis of flow characteristics through computer modeling, which changes depending on the parameters and the physical properties (Govier and Aziz, 1972) of the mixture. We have already analyzed these characteristics under steady state flow. (Yoon et al., 1996, and Yoon et al., 1997) However, in reality, this analysis can not be explained from the numerical experiment. This study will perform a computer model the unsteady state flow characteristics generated from the early stage of experimental operating. Therefore, the purpose of this study is to understand the change of the concentration of the mixtures in the pipe, the velocity of the mixtures and the distribution of the pressure from the injecting zone to the upper zone in the lift pipe.

UNSTEADY STATE FLOW MODEL OF AIR-SOLID-LIQUID MIXTURES IN THE LIFT PIPE

Generally, the equations of the unsteady state flow for three phase flow need a total of six equations in three phases, one momentum and one continuity equation per phase (Bird et al, 1960, and Hoffmann, 1989), which excluded the thermal energy equations in isothermal flow system. In this study, the modeling for the unsteady state flow consists of the continuity equations of air and pseudo solid-liquid mixtures, the momentum equations of air and pseudo solid-liquid mixtures, and the empirical constitutive equation needed for the frictional resistance between wall in the lifting pipe and the pseudo mixtures.(Lockhart and Martinelli, 1949) The following assumptions are needed : 1) the air density is a function of pressure only; 2) the mixture of water and nodules is incompressible ; 3) the slip ratio of air and water is almost same ; 4) the density of three phase flow is decided from the ratio of hold up. On the other hand, the initial condition for the flow analysis is that sea water only exists without sea water velocity and air pressure in the pipe. The boundary condition is used by calculating the flux of air depending on the air pressure and volume ratio in the air inlet, and by calculating the volume ratio and the flux of air and compounds of three phases under the atmosphere in the outlet. Three following equations are specified from the basic governing equations as above mentioned, and Eqn. 1 is the continuity equation of air phase, Eqn. 2 is the continuity equation of pseudo nodule-sea water phase mixtures, the Eqn. 3 is the momentum equation composed of the pseudo phase mixtures with air, nodules and sea water, and Eqn. 4 is the constitutive equation of pseudo phase mixtures. Finally, Eqn. 5 is characterized as a vector form of the ordinary differential equations including above the equations components.

$$\frac{\partial}{\partial t}(c_A \rho_A) + \frac{\partial}{\partial x}(c_A \rho_A v_A) = 0 \tag{1}$$

$$\frac{\partial}{\partial t}(c_M \rho_M) + \frac{\partial}{\partial x}(c_M \rho_M v_M) = 0 \tag{2}$$

$$\frac{\partial}{\partial t}(c_A \rho_A v_A) + \frac{\partial}{\partial t}(c_M \rho_M v_M) + \frac{\partial}{\partial x}(\rho_{MM} v_{MM}{}^2) + g\frac{\partial P}{\partial x} + c_A g(\rho_A - c_L \rho_M) + F = 0 \tag{3}$$

$$F = \frac{\lambda \rho_{MM} v_{MM} |v_{MM}|}{2D} \tag{4}$$

Eqns. 1, 2 and 3 are used to solve the primary dependent variables such as air volume fraction, air velocity, and pressure respectively. Above three equations can be rearranged in partial differential from as Eqns. 5, 6 and 7 including three unknown variables.

$$-\frac{\partial c_A}{\partial t} - \frac{S_M}{S_A} v_A \frac{\partial c_A}{\partial x} + (1.0 - c_A)\frac{S_M}{S_A}\frac{\partial v_A}{\partial x} = 0 \tag{5}$$

$$P\frac{\partial c_A}{\partial t} + c_A\frac{\partial P}{\partial t} + v_A P\frac{\partial c_A}{\partial x} + c_A P\frac{\partial v_A}{\partial x} + c_A v_A\frac{\partial P}{\partial x} = 0 \tag{6}$$

$$\left(\frac{\rho_0}{P_0}Pv_A - \frac{S_M}{S_A}\rho_M v_A\right)\frac{\partial c_A}{\partial t} + \left(\frac{\rho_0}{P_0}Pc_A + \frac{S_M}{S_A}\rho_M - \frac{S_M}{S_A}\rho_M c_A\right)\frac{\partial v_A}{\partial t}$$

$$+\frac{\rho_0}{P_0}c_A v_A\frac{\partial P}{\partial t} + \left(1+\frac{S_M}{S_A}\right)^2 v_A^2\left(\frac{\rho_0}{P_0}P - \rho_M\right)\frac{\partial c_A}{\partial x}$$

$$+2\rho_{MM}\left(1+\frac{S_M}{S_A}\right)^2 v_A\frac{\partial v_A}{\partial x} + \left\{\frac{\rho_0}{P_0}\left(1+\frac{S_M}{S_A}\right)^2 v_A^2 c_A + g\right\}\frac{\partial P}{\partial x} + R = 0 \qquad (7)$$

In Eqns. 5, 6 and 7, air pressure and volume under the isothermal condition as above mentioned can be expressed by Eqns. 8 and 9, and 10.

$$PV = zRT = Constant \qquad (8)$$

$$P_0\left(\frac{m}{\rho_0}\right) = P\left(\frac{m}{\rho_A}\right) \qquad (9)$$

$$\rho_A = \frac{\rho_0}{P_0}P \qquad (10)$$

Where, air density may be changed by pressure only because air is slightly compressible, while the density of the two phase mixtures with nodules and sea water is always constant because of incompressible phase. The velocity ratios of air and nodule-sea water mixtures are given in Eqn. 12 respectively, and the relation of volume fraction between air and nodule-sea water mixtures is given in Eqn. 13, and R in above Eqn. 7 is given by Eqn. 14.

$$S_A = \frac{v_A}{v_A + v_M} \qquad (11)$$

$$S_M = \frac{v_M}{v_A + v_M} \qquad (12)$$

$$c_A + c_M = 1.0 \qquad (13)$$

$$R = F_D + c_A g\left(\frac{\rho_0}{P_0}P - \rho_L\right) \qquad (14)$$

Therefore, Eqns. 1, 2, and 3 are characterized as Eqn. 15, a vector form of the ordinary difference equations including above the equations components. In Eqn. 15, the vector of the dependent variables $\vec{Q}$ is given by Eqn. 16, and the coefficients of the matrix [A], [B], and [E] are given in the Appendix.

$$\begin{vmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{vmatrix} \frac{d}{dt}\vec{Q} + \begin{vmatrix} B_{11} & B_{12} & B_{13} \\ B_{21} & B_{22} & B_{23} \\ B_{31} & B_{32} & B_{33} \end{vmatrix} \frac{d}{dt}\vec{Q} + \begin{bmatrix} E_1 \\ E_2 \\ E_3 \end{bmatrix} = 0 \tag{15}$$

$$\vec{Q} = \begin{bmatrix} c_A \\ v_A \\ P \end{bmatrix} \tag{16}$$

Finally, after applying the initial condition including from Eqn. 17 to Eqn. 20, and the boundary condition including from Eqn 21 to Eqn. 29 into Eqn. 15, the solution can be obtained by numerical computational modeling as FDM.(Dukler et al, 1964, and Mukherjee et al, 1983, and Beggs et al, 1973, and Adewumi et al, 1987) In order to solve the solution, the initial condition and the boundary condition are as follows.

Initial and Boundary Condition

The Finite difference equation to describe unsteady state phenomena of air-sea water-solid three phase mixtures is required to specify a set of initial and boundary conditions in the vertical air lifting system.

Initial condition

An initial condition is a requirement for which the dependent variables are specified in some initial state. In the initial conditions of this numerical model, there is only sea water fully developed in the air lift pipe, air velocity and pressure are assumed to be zero. And hence, they are given by Eqns. 17, 18, 19, and 20.

$$c_A = 0.0 \tag{17}$$

$$c_M = 1.0 \tag{18}$$

$$P = 0 \tag{19}$$

$$v_A = 0 \tag{20}$$

Boundary condition

A boundary condition is a requirement that the dependent variable or its derivative must satisfy on the boundary of the partial difference equation. As the boundary condition in this numerical model, at the inlet of the air lift pipe, the air volume fraction and air pressure are specified, and then air velocity can be calculated using numerical modeling. At the outlet of the air lift pipe, air pressure is specified in the atmospheric condition, and then the air velocity and the air volume fraction can be also calculated using numerical modeling. As a result, the corresponding boundary conditions are that dp/dt and dc_A/dt should be specified by zero at the inlet of the air lift pipe and that dp/dt should be specified by zero at the outlet. In order to express boundary conditions with the finite difference equations, the node number of inlet and outlet are denote by "1" an "J", respectively, and the number of time level is denoted by "n". Therefore, the air velocity at inlet can be expressed as Eqn. 21 and parameters a_1, b_1, E_1, d_1, and e_1 are defined from Eqn. 20 to Eqn. 29 as follows.

$$V_A^n\Big|_{INLET} = V_A^{n-1}\Big|_{INLET} + \frac{\Delta t}{a_1}\left\{-b_1\frac{c_{A2}^{n-1} - c_{A0}^{n-1}}{2\Delta x} - E_1\frac{V_{A2}^{n-1} - V_{A0}^{n-1}}{2\Delta x} - d_1\frac{P_2^{n-1} - P_0^{n-1}}{2\Delta x} - e_1\right\} \tag{21}$$

$$a_1 = \left(\frac{\rho_0}{P_0}P_1 c_{A1} + \frac{S_M}{S_A}\rho_{M1} - \frac{S_M}{S_A}\rho_{M1}c_{A1}\right) \tag{22}$$

$$b_1 = \left(1+\frac{S_M}{S_A}\right)^2\left(\frac{\rho_0}{P_0}P_1 - \rho_{M1}\right)V_{A1}^2 \tag{23}$$

$$E_1 = 2\left(1+\frac{S_M}{S_A}\right)^2\rho_{MM1}V_{A1} \tag{24}$$

$$d_1 = \frac{\rho_0}{P_0}\left(1+\frac{S_M}{S_A}\right)^2 c_{A1}V_{A1}^2 + g \tag{25}$$

$$c_{A0}^{n-1} = 2c_{A1}^{n-1} - c_{A2}^{n-1} \tag{26}$$

$$V_{A0}^{n-1} = 2V_{A1}^{n-1} - V_{A2}^{n-1} \tag{27}$$

$$P_0^{n-1} = 2P_1^{n-1} - P_2^{n-1} \tag{29}$$

Also, at the outlet, in order to solve the air volume fraction and the air velocity, first the air volume fraction can be calculated by Eqn. 30, finally the air velocity can be calculated by Eqn.35, the parameters of Eqn. 30 and Eqn. 44, respectively. In this manner, the unsteady state phenomena and characteristics of the three phase mixtures can be described by using given inlet and outlet boundary conditions in the air lifting system.

$$c_A^n\Big|_{OUTLET} = c_A^{n-1}\Big|_{OUTLET} + \frac{\Delta t}{a_2}\left\{-b_2\frac{c_{AJ+!}^{n-1} - c_{AJ-1}^{n-1}}{2\Delta x} - E_2\frac{V_{AJ+1}^{n-1} - V_{AJ-1}^{n-1}}{2\Delta x} - d_2\frac{P_{J+1}^{n-1} - P_{J-1}^{n-1}}{2\Delta x}\right\} \tag{30}$$

$$a_2 = P_J + 1 \tag{31}$$

$$b_2 = \frac{S_M}{S_A} u_{AJ} + v_{AJ} P_J \tag{32}$$

$$E_2 = c_{AJ} P_J - \frac{S_M}{S_A} + \frac{S_M}{S_A} c_{AJ} \tag{33}$$

$$d_2 = c_{AJ} v_{AJ} \tag{34}$$

$$\begin{aligned} v_A{}^n\Big|_{OUTLET} &= v_A{}^{n-1}\Big|_{OUTLET} - \frac{s}{a_3}\left(c_A\Big|_{OUTLET}{}^n - c_A\Big|_{OUTLET}{}^{n-1} \right) \\ &+ \frac{\Delta t}{a_3}\left\{ -b_3 \frac{c_{AJ+1}{}^{n-1} - c_{AJ-1}{}^{n-1}}{2\Delta x} - E_3 \frac{v_{AJ+1}{}^{n-1} - v_{AJ-1}{}^{n-1}}{2\Delta x} \right. \\ &\left. - d_3 \frac{P_{J+1}{}^{n-1} - P_{J-1}{}^{n-1}}{2\Delta x} - e_3 \right\} \end{aligned} \tag{35}$$

$$s = \left(\frac{\rho_0}{P_0} P_J v_{AJ} - \frac{S_M}{S_A} \rho_{MJ} v_{AJ} \right) \tag{36}$$

$$a_3 = \left(\frac{\rho_0}{P_0} P_J c_{AJ} + \frac{S_M}{S_A} \rho_{MJ} - \frac{S_M}{S_A} \rho_{MJ} c_{AJ} \right) \tag{37}$$

$$b_3 = \left(1 + \frac{S_M}{S_A} \right)^2 \left(\frac{\rho_0}{P_0} P_J - \rho_{MJ} \right) v_{AJ}{}^2 \tag{38}$$

$$E_3 = 2\left(1 + \frac{S_M}{S_A} \right)^2 \rho_{MMJ} v_{AJ} \tag{39}$$

$$d_3 = \frac{\rho_0}{P_0} \left(1 + \frac{S_M}{S_A} \right)^2 c_{AJ} v_{AJ}{}^2 + g \tag{40}$$

$$e_3 = \left(1 + \frac{S_M}{S_A} \right)^2 \frac{\lambda \rho_{MMJ} v_{AJ}{}^2}{2D} + \left(\frac{\rho_0}{P_0} P_J - \rho_L \right) g c_{AJ} \tag{41}$$

$$c_{AJ+1}{}^{n-1} = 2c_{AJ}{}^{n-1} - c_{AJ-1}{}^{n-1} \tag{42}$$

$$v_{AJ+1}{}^{n-1} = 2v_{AJ}{}^{n-1} - v_{AJ-1}{}^{n-1} \tag{43}$$

$$P_{J+1}{}^{n-1} = 2P_J{}^{n-1} - P_{J-1}{}^{n-1} \tag{44}$$

RESULTS AND DISCUSSIONS

Construction of computer modeling

Fig.1 shows the air lift system. For computer modeling in this study, we applied that the inner diameter of the lift pipe, on the basis of 0.5 and 0.3m reflecting the characteristics of the difference in inner diameters of lift pipes. Also, the length of the lift pipe from the air injecting point to the outlet is modeled at 30, 50 and 100m.

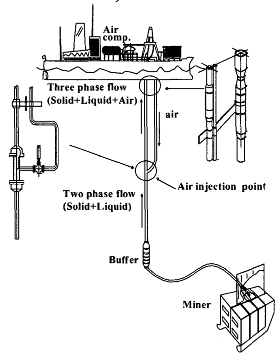

Fig. 1. Schematic view of air lifting system.

Experiment for computer modeling

Fig. 2 shows the air velocity out of the mixed fluid of air, sea water and nodules depending on the time at different positions. The time reached to steady state is about 3 seconds from the injecting point, about 7 seconds from the middle position of the lifting pipe and 10 seconds from the outlet. At the injecting point, the velocity gradually repeats a cycle of increase-decrease-increase and becomes finally constant. This is due to the injecting velocity of air increasing suddenly because the sea water in the lift pipe does not contain air pressure. At this time, air pressure increases downward from the injecting point and then reaches equilibrium, so that the velocity decreases. After this time, air pressure becomes constant, so that the velocity becomes constant. The middle position of the lift pipe is in the same situation as the injecting point. The continuous air injection increases the air volume fraction, which makes the air velocity increase to equilibrium. The discharge of air begins from the position passed 4 seconds from the outlet of lift pipe, in which the air volume fraction gradually increases. The velocity decreases first and then increases between 8 and 9 seconds. This is because air pressure increases below the outlet and air pressure decreases by the boundary condition of the outlet to reach equilibrium state. Fig. 3 shows the air volume fraction in the lift pipe depending on the time. As shown in the figure, the time that air arrives to the middle position of the lifting pipe and to the outlet is about 2 seconds and 4 seconds, respectively. This means that the air volume fraction gradually increases on going to the upper part of the lift pipe. Fig. 4 shows the mass flow rate of air out of the mixed fluid of air, sea water and nodules depending on time. It increases from the air injecting point to 2 seconds, decreases after that, and maintains a constant of 0.8kg/sec after 3 seconds. At the middle position, the velocity and air volume fraction increase until 5 seconds. Because of the decrease of air pressure in the lift pipe to reach the equilibrium state, it decreases from 5 to 6 seconds and then stabilizes at around 0.8kg/sec. Fig. 5 shows the mass flow ratio of sea water out of the mixed fluid with respect to time. At the air injecting point, the mass flow rate of sea water increases suddenly with the air velocity in early stage, but it decreases as the volume fraction of air gradually increases, and thus the mass flow rate of sea water will be about 50.0kg/sec after 3 seconds. Also, at the middle point of the lift pipe, the mass flow rate of sea water increases until 220.0kg/sec and after 7 seconds, it stabilizes at 50kg/sec. On the other hand, at outlet of the lift pipe, the sea water is discharged after 4 seconds. At this time, the mass flow rate of sea water increases to 220.0kg/sec and it is discharged at 50kg/sec after 10 seconds. Fig. 6 represents the pressure distribution in the lift pipe from the initial time to the time of steady state in the system operation. The pressure at the air injecting point is set to 5 bar and the pressure of outlet 1 bar. The air pressure in the lift pipe at the initial time is ignored. The pressure distribution at 10 seconds, which is the time of the steady state, decreases from the lower part and is closed to the atmosphere going up to the upper part. However, when the system is operated, the pressure increases from the lower part, but decreases in the lower part. This is because at the initial time the sea water has no air volume fraction according to the progress of air flow so that the pressure rising returns to the equilibrium state according to the approach of the flowing parameters of the circumstance to the equilibrium state. Fig. 7 shows that the air volume fraction in the lift pipe has many forms until the system reaches to the steady state. The flow solution can be calculated according to the boundary conditions of pressure in the outlet of the upper part by the lift volume of sea water by hold up at the air injecting point. At this state, the air volume fraction increases in going up to the upper part of the lift pipe when the system operation progresses and finally it gradually increases in the upper part if the steady state is reached. This is due to the reduction of the buoyancy force because the pressure of the upper part decreases compared to that of the lower part.

Determination and experimental usage of flow parameters for an experimental modeling

As shown in Table 1, when air is injected, if pressure, air velocity and volume fraction at outlet have no change as a function of velocity and air volume fraction at the outlet and the diameter of lift pipe, it is defined to the time of steady state. In the unsteady state, the pressure and the air volume fraction are set up at the air injecting part and outlet, so that computer modeling is started. Generally, as the injecting depth of air increases, the time to reach steady state increases and air volume fraction at the air injecting point decreases. This is because the above mentioned flow resistance of fluid totally increases. This is important as when the diameter of the lift pipe increases, the time to reach to steady state decreases so that the stabilizing effect of the system operation increases. On the other hand, even though the diameter of the lift pipe increases, the air volume fraction at the outlet is not greatly changed and the air velocity decreases, so that the effect of friction resistance decreases.

Table 1. Simulated parameters for experimental air lifting system.

Depth	Pipe Dia.	Unsteady State						Steady State						Reaching Time
		Inlet			Outlet			Inlet			Outlet			
(m)	(mm)	P(bar)	V_A(fm/s)	C_A(frac.)	P(bar)	V_A(fm/s)	C_A(frac.)	P(bar)	V_A(fm/s)	C_A(frac.)	P(bar)	V_A(fm/s)	C_A(frac.)	(sec.)
30	150	5.0	calc	0.70	1.0	calc	calc	5.0	9.5	0.70	1.0	21.1	0.93	10.0
	200	6.0	calc	0.60	1.0	calc	calc	6.0	8.9	0.60	1.0	21.7	0.91	8.5
	250	7.0	calc	0.43	1.0	calc	calc	7.0	8.1	0.43	1.0	21.4	0.88	8.1
	300	7.5	calc	0.50	1.0	calc	calc	7.5	8.7	0.50	1.0	23.4	0.90	7.5
50	150	5.0	calc	0.50	1.0	calc	calc	5.0	8.2	0.50	1.0	15.6	0.86	20.0
	200	6.0	calc	0.50	1.0	calc	calc	6.0	8.9	0.50	1.0	19.8	0.88	15.0
	250	7.0	calc	0.43	1.0	calc	calc	7.0	8.9	0.43	1.0	21.4	0.87	13.0
	300	7.5	calc	0.43	1.0	calc	calc	7.5	9.3	0.43	1.0	24.5	0.89	12.0
100	150	4.0	calc	0.35	1.0	calc	calc	4.0	7.9	0.35	1.0	11.6	0.74	50.0
	200	5.0	calc	0.20	1.0	calc	calc	6.0	8.2	0.20	1.0	13.8	0.74	37.0
	250	7.0	calc	0.22	1.0	calc	calc	7.0	8.9	0.22	1.0	17.4	0.79	28.0
	300	7.5	calc	0.25	1.0	calc	calc	7.5	9.6	0.25	1.0	21.3	0.83	25.0

Remark: Characterized "calc" is the variable simulated from numerical modeling.

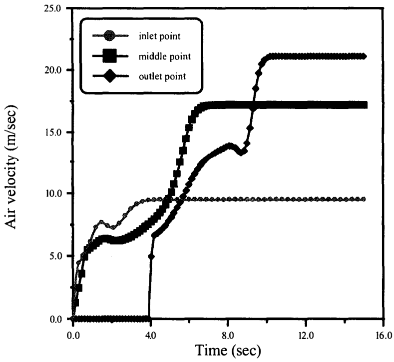

Fig. 2. Air velocity versus time at pipe positions.
(pipe dia. 0.1 5m, lifting length 30m)

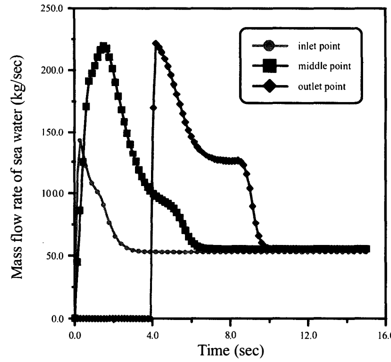

Fig. 5. Mass flow rate of sea water versus time at pipe positions.
(pipe dia. 0.15m, lifting length 30m)

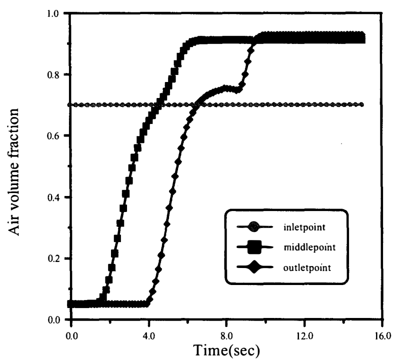

Fig. 3. Air volume fraction versus time at pipe positions.
(pipe dia. 0.15m, lifting length 30m)

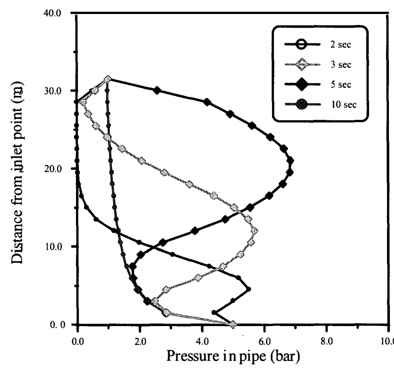

Fig. 6. Pressure distribution in pipe for reaching the steady state.
(pipe dia. 0.15m, lifting length 30m)

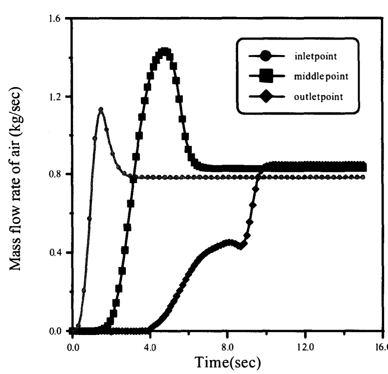

Fig. 4. Mass flow rate of air versus time at pipe positions.
(pipe dia. 0.15m, lifting length 30m)

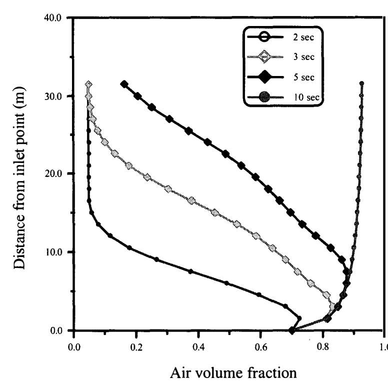

Fig. 7. Air volume fraction distribution in pipe for reaching the steady state. (pipe dia. 0.15m, lifting length 30m)

CONCLUSION

1. As the lifting depth increases, the arrival time to steady state increases, but if it increases, the air volume fraction and air velocity at the inlet decrease in the steady state because the drag force of the fluid totally decreases.
2. When the diameter of lift pipe increases, the arrival time to steady state decreases, so that the stabilizing effect on system operation increases.
3. The air volume fraction at the outlet in the steady state does not greatly change even though the diameter of the lift pipe increases and it increases near the outlet of the lift pipe as air expands.
4. This model experiment minimizes the error which could be made engineering trials.

NOMENCLATURES

$A_{11}\sim$, $B_{11}\sim$, $E_{11}\sim$	=	component elements of flux vectors
C	=	volume fraction, fraction
D	=	pipe diameter, L
F	=	frictional resistance force per unit volume, M/L^2T^2
g	=	gravitational acceleration, L/T^2
P	=	pressure, M/LT^2
t	=	time variable, T
v	=	superficial velocity, L/T
x	=	pipe axial variable, L
ρ	=	density, M/L^3
λ	=	friction coefficient, fraction

Subscripts

L	=	sea water phase
A	=	air phase
M	=	pseudo solid-water mixtures phases
MM	=	pseudo air-solid-water mixtures phases

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APPENDIX

The component elements of flux vectors in Eqn. 15 can be expressed as follows :

$$A_{11} = -1.0$$
$$A_{12} = A_{13} = 0$$
$$A_{21} = P$$
$$A_{22} = 0$$
$$A_{23} = c_A$$
$$A_{31} = \frac{\rho_0}{P_0} P v_A - \frac{S_M}{S_A} \rho_M v_A$$
$$A_{32} = \frac{\rho_0}{P_0} P c_A + \frac{S_M}{S_A} \rho_M - \frac{S_M}{S_A} \rho_M c_A$$
$$A_{33} = \frac{\rho_0}{P_0} c_A v_A$$
$$B_{11} = -\frac{S_M}{S_A} v_A$$
$$B_{12} = \frac{S_M}{S_A}\left(1.0 - c_A\right)$$
$$B_{13} = 0$$
$$B_{21} = v_A P$$
$$B_{22} = c_A P$$
$$B_{23} = c_A v_A$$
$$B_{31} = \left(1 + \frac{S_M}{S_A}\right)^2 \left(\frac{\rho_0}{P_0} P - \rho_M\right) v_A^2$$
$$B_{32} = 2\rho_{MM}\left(1 + \frac{S_M}{S_A}\right)^2 v_A$$
$$B_{33} = \frac{\rho_0}{P_0}\left(1 + \frac{S_M}{S_A}\right)^2 c_A v_A^2 + g$$
$$E_1 = E_2 = 0$$
$$E_3 = \left(1 + \frac{S_M}{S_A}\right)^2 \frac{\lambda \rho_{MM} v_A^2}{2D} + \left(\frac{\rho_0}{P_0} P - \rho_L\right) g c_A$$

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