CHAPTER 222

Model of Bivalve On/offshore Movement by Waves

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Abstract

This study aimed to develop a numerical method of calculating bivalve movement by waves, and to consider the validity of this model with comparison between the calculated distribution of bivalves and real sampled data. The distribution of bivalves calculated by this numerical method coincided well with the real sampled data. This numerical method can predict the difference of distribution according to shell length, specific gravity of bivalve, shape of bivalves and so on. Thus, this method will be able to explain the mechanism of zonation of bivalves.

Introduction

It has been generally thought that the fishing productivity is low for sandy beach facing the open sea. However, only a few studies about the fishing productivity of sandy beaches have been performed in Japan because of severe sea conditions such as the surf zone. Therefore, almost no technology exists to develop the sandy beaches as fishing grounds.

Many bivalves live in the dissipative exposed sandy beach. These include species commercially important as fishery resources, for example, Meretrix lamarckii, Gomphina melanaegis, Pseudocardinm sachalinensis and so on. We believe that the movement of bivalves by waves is closely related to the formation of grounds for their fishing. Therefore, it is very important to study the movement of bivalves for the development of fishing grounds.

On the other hand, recently, the development of

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waterfronts has attracted our attention in Japan and many kinds of artificial facilities have been constructed. Those facilities change the physical environment around them, such as wave velocity, wave direction and so on. It means that bivalves incur risks of being moved to other places where the environment is undesirable for them. We need to predict how such facilities will affect the movement of bivalves, if we are afraid of destruction of the coastal ecosystem.

The study on the movement of bivalves by waves is important not only for the improvement of fishing ground but also for environmental conservation of the sandy coastal zone.

Since 1986, we have studied the relationship between the beach profile and the distribution of bivalves in the surf zone utilizing the pier of the Hasaki Oceanographic Research Facility (HORF) of the Port and Harbor Research Institute. From numerous investigations, we found the following:

1. Passive movement by waves is more important for the distribution of bivalves than their own motility.
2. The distribution of bivalves is related to physical conditions, such as waves, the beach profile, the bivalve and so on.

Therefore, it is considered possible to analyze the mechanism of bivalve movement numerically, based on civil engineering methods.

From these points of view, this paper proposes a numerical method that predicts the movement of bivalves by waves. The wave field is calculated with a time-dependent mild slope equation. The bivalve model is expressed by specific gravity, shell length, coefficient of mass force and drag force and so on. The moving distance is calculated for bivalves at any place and time. After that, we consider the validity of the numerical method with comparison between the calculated distribution of model bivalves and the real sampled data at HORF. The field survey of distribution of bivalves has been carried out by both the National Research Institute of Fishery Engineering and the Port and Harbor Research Institute.

Numerical Method

This numerical method consists of three calculation steps as follows:

1) of the wave field.
2) of the distance a bivalve is moved by one wave.
3) of the distance a bivalve is moved by cyclic waves.

Through these steps, we can predict the moving distance is calculated for bivalves at any place and time.

Wave Field

We calculated the wave field in the on/offshore including the surf zone at an optional beach profile with the time-dependent mild slope equations as follows (Watanabe and Maruyama, 1984).

$$\frac{\partial Q_x}{\partial t}+c^2\frac{\partial \zeta}{\partial x}+f_D Q_x=0 \tag{1}$$

$$\frac{\partial \zeta}{\partial t}+\frac{1}{n}\frac{(\partial n Q_x)}{\partial x}=0 \tag{2}$$

where Q_x denotes $\int udz$ (u: horizontal component of wave orbital wave, z: vertical coordinate), ζ: water surface elevation, c: wave celerity, n: 1/2(1+2kh/sinh2kh), k: wave number, h: water depth, f_D: damping coefficient by wave breaking, x: horizontal coordinate, t: time.

The determination of wave breaking point depends on the ratio of orbital velocity and celerity of the wave (Isobe, 1986).

The wave orbital velocity on the seabed is shown as follows. This equation is given by the small amplitude theory.

$$u_{bv}=kQ_x\sin(\sigma t+\epsilon_x)/\sinh(kh) \tag{3}$$

where ε_x denotes phase difference, σ: angular frequency (= 2π/T, T: wave period).

In the surf zone, the flow in the offshore direction, the undertow, occurs when the breaking waves generate mass flux in the onshore direction. Eq.(4) denotes the undertow velocity calculated by Sato et al.(1987). It is assumed that the distribution of undertow is the largest value at the making point of bore and decreases linearly from this point to 10 times breaking water depth in the offshore direction. Eq.(5) shows the distance between the wave breaking point and the making point of bore (Okayasu et at., 1990). Eqs.(4) and (5) are experimentally obtained.

$$U_{br}=A\frac{H^2}{hT} \tag{4}$$

$$l_t = \left(\frac{1}{5\tan\beta} + 4\right) h_b \qquad (5)$$

where A denotes experimental constant, H: wave height, h_b: breaking water depth, β: beach slope near breaking point. In this calculation step, we aim to calculate the wave and flow on seabed which acts on the bivalve.

Bivalve Movement by One Wave

Figure 1 shows the bivalve movement model. For bivalves with shell length D on the seabed with slope β, the bivalves move at velocity u_s due to the wave bottom velocity u_b. It is assumed that bivalves are passively moved by waves and move on the surface of the bottom by sliding. The components of forces acting on the bivalve are also shown in Figure 1.

1) the force caused by the pressure gradient of waves: $m du_b/dt$
2) the mass force cased by the relative movement between bivalve and fluid: $C_M m(du_b/dt - du_s/dt)$
3) the drag force caused by the relative velocity: $1/2 C_D \rho_w A(u_b - u_s)|u_b - u_s|$
4) the component of gravity parallel to the seabed surface: $g(M-m)\sin\beta$
5) the frictional resistance force caused by sliding of the bivalve on the seabed: $-\mu_f g(M-m)\cos\beta\, u_s/|u_s|$.

where M denotes mass of bivalve ($1/6\pi\rho_s D^3$, ρ_s: specific gravity of bivalve), m: mass of water ($1/6\pi\rho_w D^3$, ρ_w: specific gravity of water), C_M, C_D :coefficient of apparent mass force and drag force respectively, A: area of the bivalve that projects, μ_f: the frictional resistance coefficient. However, μ_f in this numerical method is

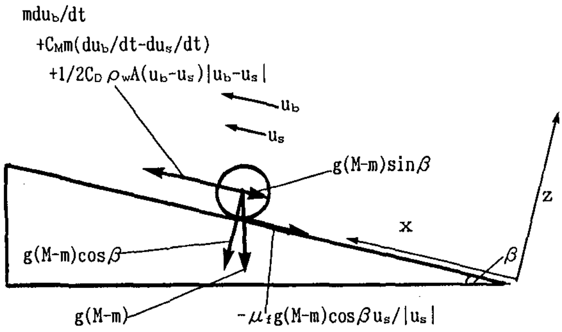

Figure 1. Bivalve Movement Model By Wave.

defined as the coefficient of the degree of movement, which includes the effect of burrowing, rough ripple and so on. Thus, we assumed that the bivalve was moved by the balance of these forces.

The resulting equations of motion of bivalve by wave are shown as follows. These equations are able to express Lagrangian analysis of bivalve movement, when the orbital velocity on the seabed is precisely given at the moved position of bivalve.

$$\frac{dX(t)}{dt}=u_s(t) \tag{6}$$

$$\begin{aligned} M\frac{du_s(t)}{dt} &= m\frac{du_b(X,t)}{dt}+C_M m\frac{d(u_s(t)-u_b(X,t))}{dt} \\ &+\frac{1}{2}C_D A\rho_w |u_b(X,t)-u_s(t)|(u_b(X,t)-u_s(t)) \\ &-(M-m)g\sin\beta-\mu_f g(M-m)\cos\beta\frac{u_s(t)}{|u_s(t)|} \end{aligned} \tag{7}$$

The bivalve starts to move when the total of the drag force and the mass force exceeds the total of the gravity and the frictional resistance force. The bivalve stops when the velocity of the bivalve becomes zero. In addition, the frictional resistance coefficient used is the static one when the bivalve stops and is the dynamic one when the bivalve moves. These equations are calculated by the Runge-Kutter-Gill method. In this calculation step, the distance the bivalve is moved by one wave is calculated at each position of the whole beach.

Bivalve Movement by Cyclic Waves

The number of cyclic waves and the position and the number of bivalve individuals are given. The bivalve movement by the cyclic waves is able to be calculated by piling the moving distance by one wave which is given at the previous calculation step.

Method of Field Survey & Conditions of Numerical Calculation

The investigation was carried out at the HORF research pier. This pier is on the Hasaki coast in Ibaragi Prefecture, Japan (Figure 2). The total HORF length is 427m and the deck width is 2.5m. This pier juts out into the surf zone. The distribution of bivalves has been investigated at intervals of 10m along HORF once a month since 1986 by means of the Smith-McIntyre grab (22×22cm). This investigation

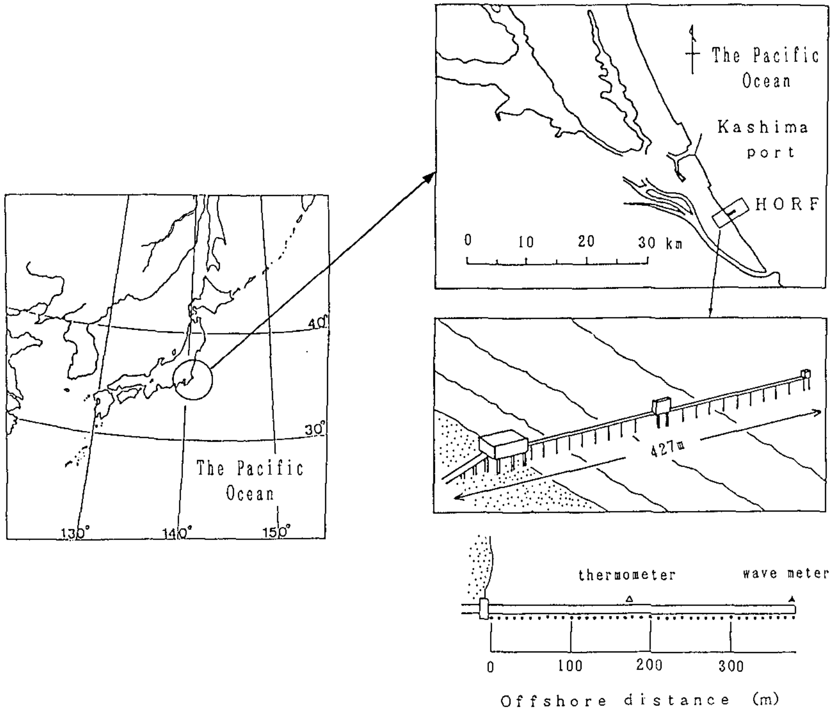

Figure 2. Study Site of Field Survey. The coast consists of exposed sandy shores facing the Pacific Ocean. Location of Hasaki Oceanographical Research Facility (HORF), water temperature meter, wave gages and sampling stations of bottom sediments(•) are shown.

method and results were described in detail by Higano et al. (1993a).

The following conditions were used in the numerical calculation. The beach profile used the field data at HORF and the tidal level used the value of the observation at 15:00, June 23, 1987. The physical characteristics of waves and bivalves were used the following values.

H_0=1.5m, T=7.0sec
D=20mm, ρ_s=1.8, C_M=0.5, C_D=0.5, μ_{fs}=1.0, μ_{fd}=0.5

The specific gravities ρ_s of Mactra crossei, M. lamarckii and G. melanaegis are 1.3, 1.6, and 1.8, respectively (Higano et al., 1993b).

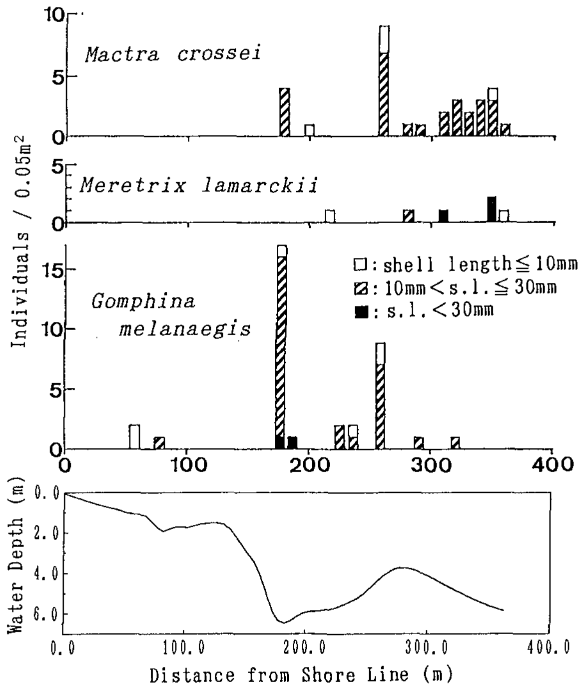

Figure 3. Beach Profile and Distribution Density of Bivalves (columns) at HORF on June 23, 1987.

Results and Discussion

Results of Field Survey (June 23,1987)

Figure 3 shows the distributions of three bivalve species and the beach profile at HORF, on June 23, 1987. The beach profile indicated the trough largely scoured by a storm a few days previously. The onshore side of the trough became remarkably steep. G. melanaegis were accumulated extremely densely at 180m from the shoreline. M. lamarckii tended to distribute on the offshore side of the bar. M. crossei distributed mainly on the zone farthest offshore.

Photograph 1 shows the bivalves sampled in this field: G. melanaegis, M. lamarckii and M. crossei, in order from left. These physical characteristics (for example, specific gravity, shape, roughness of bivalve surface and so on) are varied. It is considered that the physical differences of bivalves form the zonation of bivalves as shown in Figure 3.

Photo 1. Bivalves Sampled at HORF. (Left: G. melanaegis, Center: M. lamarckii, right: M. crossei)

Results of Numerical Calculation

Figure 4 shows the results of calculation of the wave field. The offshore wave is assumed to have H_0 of 1.5m and T of 7.0sec.
Figures 4 (a), (b) and (c) show the distributions of the wave height, the wave orbital velocity on the seabed and the undertow velocity, respectively. These horizontal axes show the distance from the shoreline.

The wave breaking occurred at 157m from the shoreline. The wave height, wave orbital velocity and undertow velocity were maximum near the breaking point and were damped drastically at the onshore side of the trough.

We exerted the wave orbital velocity and undertow velocity on the model bivalve and calculated the bivalve movement. Figure 5 shows the bivalve's movement by waves. The model bivalve assumed the physical characteristics of G. melanaegis. Figure 5 (a) shows the distribution of the distance moved by one wave. The vertical axis shows the moving distances of bivalves, which are taken to be positive in the onshore direction and negative in the offshore direction. Figure 5 (b) shows the movement of bivalves by the cyclic wave. The vertical axis is the passage of time. Each model bivalve was placed on the seabed at intervals of 10m along the on/offshore line in the initial condition.

Although bivalves on the offshore side of the bar and on the onshore side from 100m showed almost no movement, they moved in the onshore direction from the top of the bar to the bottom of trough and in the offshore direction on the

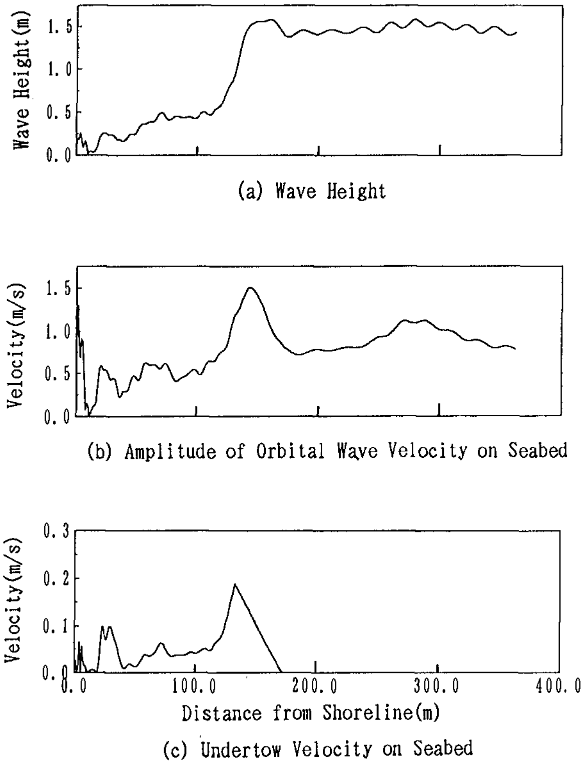

Figure 4. Results of calculation of Wave Field. (The beach profile is shown in Figure 3. The offshore wave are H_0=1.5m and T=7.0sec.)

onshore side of the trough. Bivalves were extremely densely accumulated at 180m by cyclic waves, which is the bottom of trough. This tendency was the same as the field survey in Figure 3.

After that, we varied the physical characteristics of the waves and the bivalves and tried to calculate model bivalve distributions. Figure 6 shows the results of calculated distribution of the model bivalves. Figures 6 (a), (b) and (c) show the effect of wave characteristics, shell length and specific gravity of the bivalve, respectively. Individual bivalves were counted in each section at an interval of 10m. The distributions after 10,000sec were shown.

In Figure 6 (a), although bivalves hardly moved when the wave height was 0.5m and the wave period was 5.0sec, they

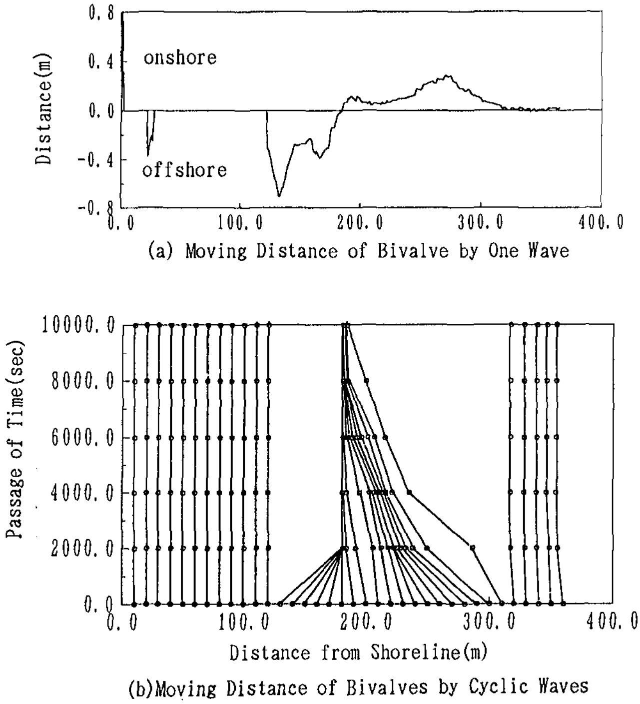

Figure 5. Bivalves Movement by Waves. The model bivalves assumed the G. melanaegis. (D=20mm, ρ_s=1.8, C_M=0.5, C_D=0.5, μ_{fs}=1.0, μ_{fd}=0.5)

accumulated in the trough when the wave height was 1.5m and the period was 7.0sec and on the top of the bar when the wave height was 2.5m and the period was 9.0sec. In Figure 6 (b), the model bivalves with shell length 5mm accumulated at 150m and 170m. Those of shell length 20mm accumulated at 180m. However, those of shell length 40mm hardly moved. In Figure 6 (c), the distribution of model bivalves of specific gravity 1.6 had the same tendency as those of specific gravity 1.8. These model bivalves accumulated at 180m. The model bivalves of specific gravity 1.3 accumulated at 150m and 170m. These calculated results coincide well with the real sampled data for G. melanegis of 10 to 30mm in diameter accumulated at the bottom of trough. But this calculated result cannot explain M. crossei in the offshore side of the bar. The reason why the results don't coincide may be that the initial distribution of bivalve at the real beach was different from that of the numerical study.

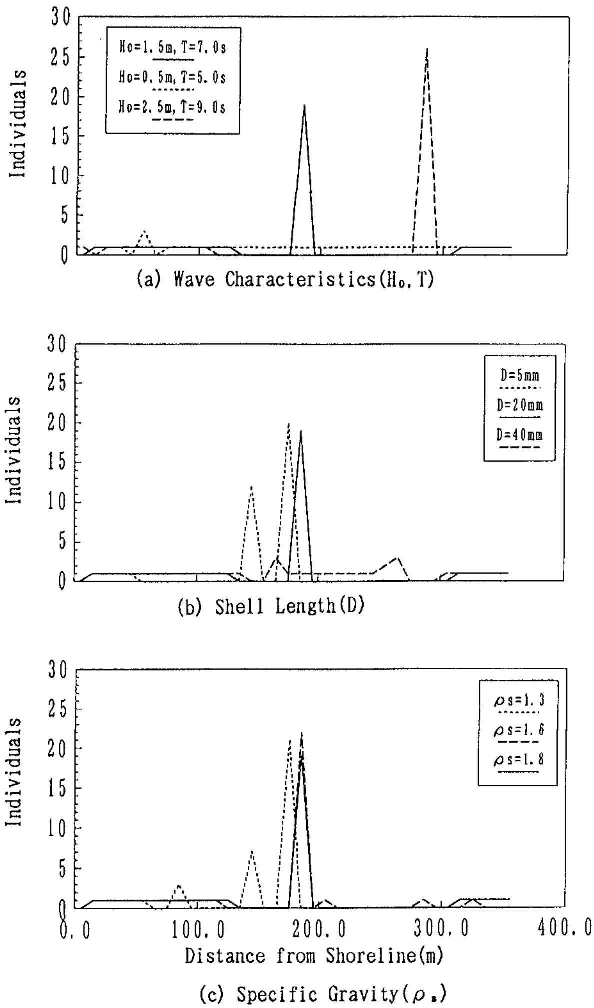

Figure 6. Relation between Distributions of Model Bivalve and Physical Characteristics of Waves and Bivalves.

Conclusion

In this study, we developed the numerical method of calculating bivalve movement by waves, and we considered the validity of this model with comparison between the calculated distribution of bivalves and the real sampled data at HORF.

As a result, the following main findings were obtained from this study:

1) This numerical method can predict the difference of distribution given the shell length, the specific gravity and so on. Thus, this method will be able to explain the mechanism of zonation of bivalves.

2) This numerical method explains the tendency which the bivalves accumulate in the trough. The result coincides well with the real accumulation of G. melanaegis.

3) But, this numerical method cannot explain the accumulation of M. crossei on the offshore side of the bar.

4) The bivalves throughout the area start to move and accumulate remarkably when the waves become severe.

As mentioned above, we found that this numerical method was useful in predicting the bivalves' movement by wave. We are conducting experimental study with the 2-dimensional wave tank. We are trying to give this numerical method more precision. This numerical prediction method will be able easily to be applied to bivalves' horizontal movement by waves. With this numerical method, we hope to contribute to the development of fishing grounds and the conservation of coastal zones.

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References

Isobe,M(1987).Parabolic equation model for transformation of irregular waves due to refraction, diffraction and breaking, Coastal Eng. Japan, Vol.30,No.1, pp.33-47.

Okayasu,A.,M.,Isobe and A.,Watanabe(1990). Experimental study on making point of bore wave breaking, Proc. 44th Annual Conf. for Civil Eng., JSCE, II, pp.614-615. (in Japanese)

Kuwahara,H. and J.Higano(1994).Analysis method on-offshore movement of bivalves by waves, Bull.N.R.I.F.E. 15, pp.25- 40 (in Japanese).

Kuwahara H.,Higano J,Nakamura Y.and N,Mimura(1994).Study on mechanism of bivalve movement by waves and validity of numerical method, Proc.41th Japanese conf. on Coastal Eng., JSCE pp.376-380 (in Japaneses).

Higano J.,K.Kimoto and Y.Yasunaga,(1993a).The change of beach profile and the distribution of sandy beach bivalves at Kashima-nada I.report of the result in 1987. Tech.Rept N.R.I.F.E. Aquacul.& Fish. Port. 14, pp.1-16 (in Japanese).

Higano J.,K.Kimoto,and Y.Yasunaga(1993b).Influence on the relation between burrowing behavior and physical environment regarding the distribution of sandy beach bivalves Meretrix lamarckii and Gomphina melanaegis. Bull.N.R.I.F.E. 14, pp.65-87(in Japanese).

Sato S.,M.Fukuhara and K.Horikawa(1987).Laboratory study on near-bottom velocity due to irregular wave, Proc.34th Japanese conf.on Coastal Eng., JSCE, pp.36-40 (in Japanese).

Watanabe A. and Maruyama Y.(1984). Numerical analysis of combined refraction, diffraction and breaking, Proc. 31st Japanese Conf.on Coastal Eng.,JSCE,pp.103-107 (in Japanese).