CHAPTER 337

EXPERIMENTAL STUDY ON THE BEHAVIOR OF BIVALVES BY OSCILLATORY FLOW

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ABSTRUCT

To improve propagation of bivalves living in exposed sandy beach, we need to clarify the behavior of bivalves affected by water waves. Using a U-shape tube, the behavior of bivalves (surf clam and sunray surf clam) in an oscillatory flow was experimentally studied. It was found that the critical condition at which bivalves are forced out of the sand into the water is determined by the ratio between the velocity of bed erosion and the burrowing rate of bivalves, and until the bivalves are forced out into the water their own movement is significant. Also the experimental values measuring their behavior on a smooth surface fixed bed was found to be theoretically explained by setting C_D(drag coefficient), C_M(added mass coefficient) and μ '(coefficient of dynamic friction) at 1.0,0.5 and 0.1, respectively. After the bivalves are forced out into the water from the sand, therefore, their behavior is hardly affected by their own movement and we can regard them as inanimate objects.

INTRODUCTION

Japanese surf clam *(Pseudocardium sybillae)* and sunray surf clam *(Mactra cinensis)*, which live in open sandy beaches along the coast of northern Japan are important fishery resources. However, there is a high mortality rate among young

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bivalves, which must be minimized to ensure their propagation.

There have been reports showing an increase in young bivalves of surf clams in tranquil areas around newly constructed ports (for example, Hayase and Miyamoto , 1985). A large number of young bivalves are often cast onto the shore by high waves in winter (Photo. 1). From these examples and other on-site investigations of the clam's population (Watanabe , 1980), waves, especially high waves during winter, have been thought to be one of the major factors responsible for the mortality of young bivalves. Therefore, the process of mortality and the behavior of young live bivalves due to waves must be clarified. As the first example above shows, bivalves are deeply related to structures built on coastlines. Therefore, for the designe of coastal structures with consideration to the surrounding environment, the influence on the bivalves by waves must be clarified.

The effects of the bivalves' own active movements (burrowing) are important for investigating the behavior of bivalves due to waves. Although some experimental studies have been carried out on the behavior of dead bivalves (Watanabe ,1982; Kuwahara ,1993,1994), except for our previous studies (Yamashita et al. 1994a,1994b,1995), very few experimental studies have been carried out on the behavior and mortality of live bivalves due to waves. The effects of the bivalves' own active movements (burrowing) under water waves have still not been estimated quantitatively.

Bivalves usually dig themselves into the sand. According to our previous studies, when the sea bed erosion and accumulation occurs due to the action of waves, the bivalves keep digging into the sand by reacting to the deformation of the sea bed. However they are sometimes forced out of the sand into the water by a sudden deformation due to high waves. This movement is thought to be the first phase in the mortality process.

In this study, the following five points were investigated in order to understand the first phase of the mortality process: (1) the critical condition of release, (2) the critical condition of burrowing, (3) the burrowing rate of bivalves, (4) the bed erosion velocity and (5) the moving velocity of bivalves on a fixed bed.

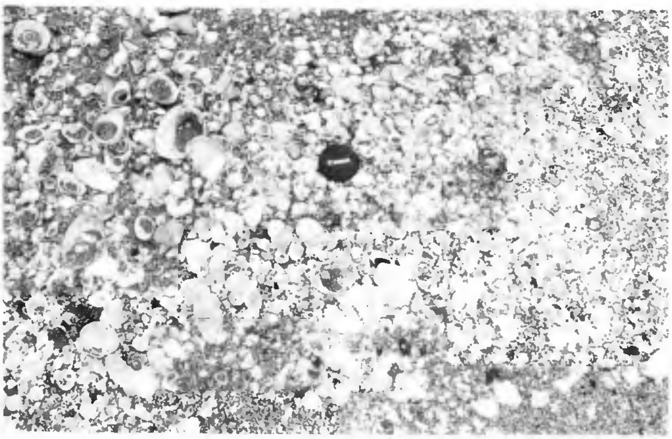


Photo.1 Young bivalves cast onto the shore in winter

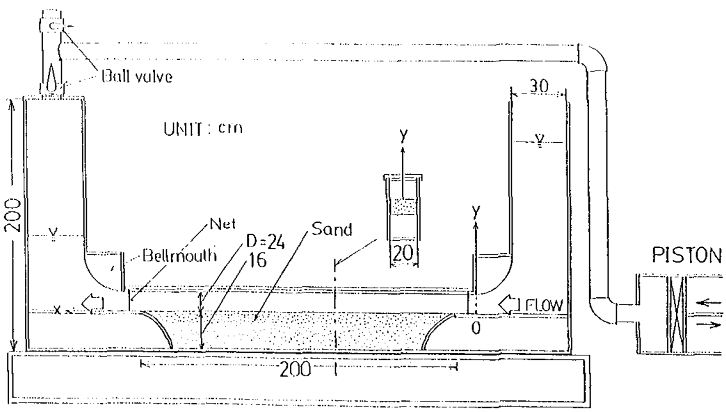


Fig.1 Schematical view of the U-shape tube

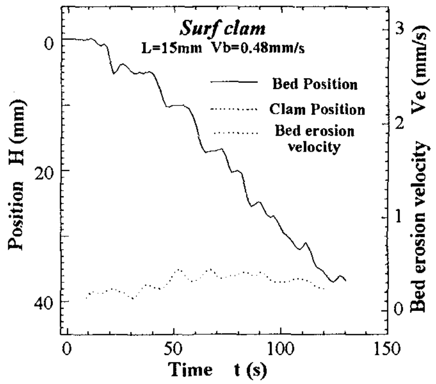
EXPERIMENTS

For the experiments, a U-shape oscillatory flow tube made of acrylic resin was used (Fig. 1). Sea water and sand were put into it. In the movable bed experiments, a 16cm-deep layer of sand, with a grain size of 0.3mm, was made at the bottom of the tube. In the fixed bed experiment, a plate made of acrylic resin with a smooth surface was used. Young live bivalves (surf clam and sunray surf clam), 5mm~ 40mm in size, were used in the experiments. The wave period was set at either 3 sec. or 3.5 sec. The amplitude of the flow velocity (Um) ranged from 20 cm/s to 90 cm/s. The water temperature was set at 16℃~22℃.

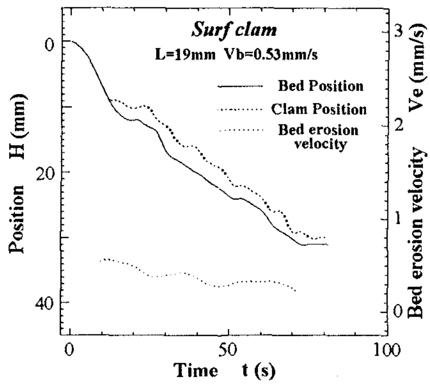
The following were investigated:

(1)the critical condition at which bivalves are forced out of the sand into the water
(2)the critical condition at which bivalves forced out into the water can burrow back into the sand again
(3)the decrease in the energy (burrowing rate) of bivalves due to a drop in water temperature
(4)the bed erosion velocity at which sand ripples are formed
(5)the behavior of bivalves forced out into the water on a fixed bed with a smooth surface.

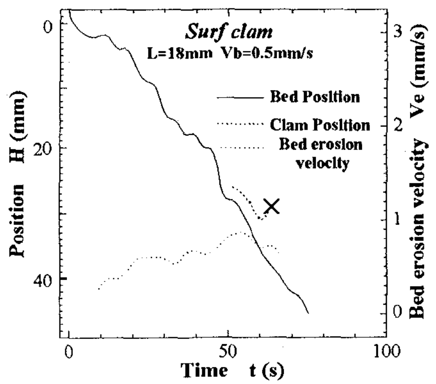
Experiments were conducted according to the following methods. Experiment (1): After the bivalves had dug themselves into the sand, we generated an oscillatory flow, and the deformation of the bed and behavior of bivalves were recorded by video camera. Experiment (2): To measure the critical flow velocity at which bivalves can burrow into the sand, bivalves were put into water where stable sand ripples had formed by varying the flow velocity. Experiment (3): We measured the burrowing rate of bivalves by changing the water temperature from 20℃ to 5℃ every 5℃ in a controlled temperature room, and investigated the relationship



(a)



(b)



(c)

Fig.2 Relation of bed erosion to burrowing behavior of a bivalve

(a) (b) The case of a bivalve remained in the sand

(c) The case of a bivalve forced out into the water

between water temperature and burrowing rate of bivalves after adapting bivalves to each water temperature for three days. Experiment (4): We measured the bed erosion velocity at which sand ripples were formed from a flat condition using a video camera. Experiment (5): We measured the moving velocities of bivalves, and compared the theoretical and experimental values.

RESULTS

(1) **Critical Condition of Release**

Fig.2 shows typical examples of sea bed deformation and the behavior of the bivalves. The velocity of the sea bed erosion was calculated hourly from the variation in bed form. Fig.2(a) shows an example where the bivalve kept digging into the sand and remained there despite erosion of the sea bed, because the velocity of the

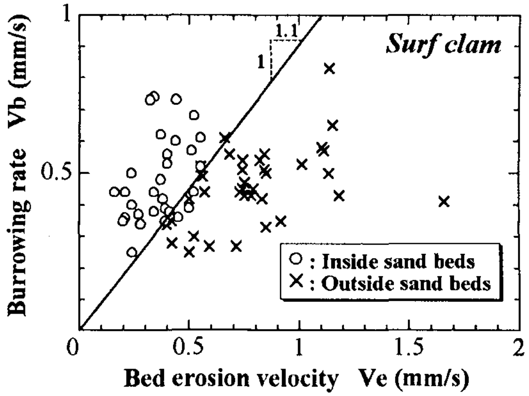


Fig.3 Critical condition at which bivalves are forced out of the sand into the water by the flow

sea bed erosion (Ve) was lower than the burrowing rate of the bivalve (Vb). Fig.2(b) shows another result. At the beginning of the experiment, the velocity of the deformation of the bed exceeded the burrowing rate of the bivalve, and only one-fifth of the shell length of the bivalve was washed out of the sand. However, later as the velocity of the bed erosion became lower than the burrowing rate of the bivalve, the bivalve remained in the sand. Fig.2(c) shows the following example. At the beginning of the experiment, the deformation of the sea bed occurred at a velocity almost equal to the burrowing rate of the bivalve, and the bivalve kept digging into the sand and remained there for 43 sec. after the experiment started. Later, as the velocity of the deformation of the bed exceeded the burrowing rate of the bivalve, the bivalve was at first partly washed out, and then completely forced out into the water. Fig.2 clearly shows that the critical condition at which the bivalves were forced out into the water is related to the bivalves' burrowing rate (Vb) and the velocity of deformation of the sea bed (Ve).

Fig.3 shows the relation between Ve and Vb based on data from 80 samples, using surf clams as Fig.2. Fig.3 shows the conditions of the bivalves with a certain burrowing rate at a certain velocity of deformation of the sea bed, which are categorized into the following: ○ indicates bivalves that remained in the sand completely, and × indicates bivalves that were completely forced out into the water. When the bivalves were washed out of the sand by about half the length of their shell, they tended to be completely forced out of the sand. Thus, the velocity of the deformation of the bed can be defined as the maximum value (Vemax) in the experiment of the mean erosion velocity at which erosion of the sea bed occurred at a depth of half of the shell length. The burrowing rate of bivalves (Vb) can be calculated by dividing the shell length (L) by the time taken for bivalves to burrow into the sand.

Fig.3 shows that the critical condition at which bivalves are forced out of the sand into the water by the flow is determined by the ratio between Ve and Vb, i.e. 1.1. The present experimental results were higher than those using dead bivalves placed on the sand. Thus, until the bivalves are forced out into the water, their own movement is important.

(2) Critical Condition of Burrowing

Fig.4 shows the results using sunray surf clams of the critical condition at which bivalves forced out into the water can burrow back into the sand. In Fig.4, ○ indicates bivalves that could burrow into the sand under the water flow, and × indicates bivalves that couldn't. The oblique line in the figure shows the critical condition. The critical flow velocity at which a bivalve with a certain burrowing rate can burrow into the sand is quantitatively obtained from this figure. It was found that when the burrowing rates of the bivalves increased, they can burrow back into the sand by themselves against higher flow velocities.

The critical flow velocity obtained in this experiment is the value that usually occurs at the sea bottom. Therefore, it seems to be difficult for bivalves which are forced out of the sand to burrow into the sand again under a rough sea for several days.

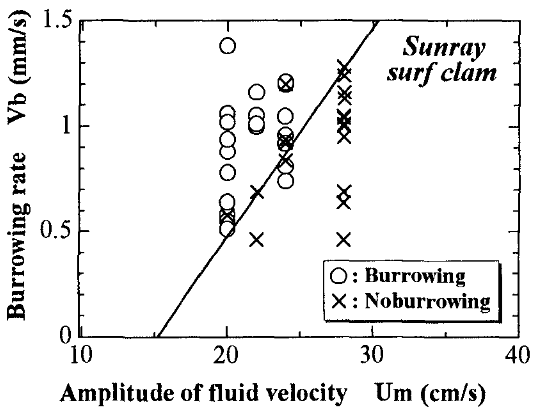


Fig.4 Critical condition at which bivalves forced out into the water can burrow back into sand again

(3) Borrowing Rate of Bivalves

The ability of the bivalves to dig into the sand by themselves greatly affects both the critical conditions at which the bivalves are forced out of the sand into the water and at which the bivalves can burrow back into the sand. Fig.5 shows one example (surf clam) of the experimental results concerning the burrowing rates of bivalves with varying water temperatures from 20℃ to 5℃. The straight lines in the figure indicate regression lines that coincide with the origin under each temperature. The result of the experiment was that the burrowing rate of bivalves below a certain water temperature is roughly proportional to the length of the shell, and decreases with a fall in water temperature.

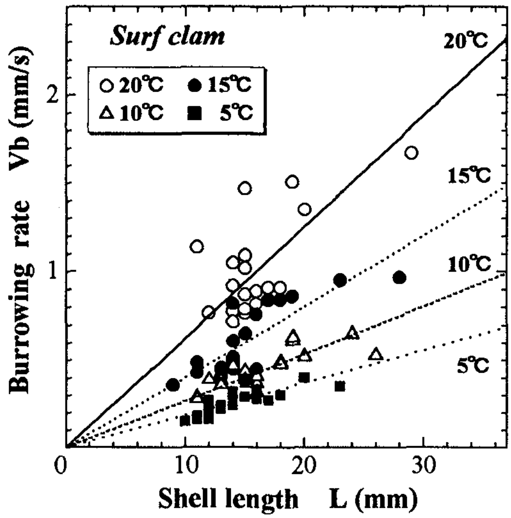


Fig.5 Relation of shel length to burrowing rate

(4) **Bed Erosion Velocity**

It was observed in Experiment (1) that the critical condition at which bivalves are forced out of the sand into the water was related to the velocity of the sea bed erosion. Bivalves tend to be forced out of the sand when sand bed are eroded about shell length in depth for a short time. Major examples of local deformation at a high velocity of topography by waves are the erosion and accumulation of sand resulting from the formation of sand ripples, the movement of sand ripples, and the large scale vortex caused by wave breaking. In this experiment, we first measured the bed erosion velocity under which sand ripples were formed from a flat condition to clarify the bed erosion velocity under which sand ripples were formed by an oscillatory flow, and then the amplitude of the flow velocity Um = 20,40,60,80 cm/s.

Under the condition where sand ripples were formed, the erosion and accumulation of the sea bed occurred complexly. The pattern of deformation of the topography showed a wide variation from 50 sec. to 2000 sec.. The release of bivalves out of the sand into the water depended on whether the velocity of the deformation of the bed exceeded the burrowing rate of the bivalves. Therefore, the probability of the bivalves being released is related locally to the probability of maximum bed erosion velocity occurring. Fig.6 shows the local probability of the maximum bed erosion velocity at which it exceeded a certain erosion velocity of the bed. In the calculation, as in Experiment (1), the maximum bed erosion velocity is defined as the maximum value in the experiment of the mean bed erosion velocity at which the erosion of the bed occurred at a depth of half of the shell length.

Fig.6(a) shows an example of the experimental results of the maximum bed erosion velocity for the bivalve with a shell length of 10mm. Fig.6(b) shows another example of the bivalve with a shell length of 30mm. These figures indicate that under the condition where the same flow velocity or deformation of the bed occurred, the shorter the length of the bivalve, the higher the bed erosion velocity related to the release of the bivalve became. Fig.6 quantitatively shows that as the amplitude of the flow velocity increased, the maximum erosion velocity of the bed increased.

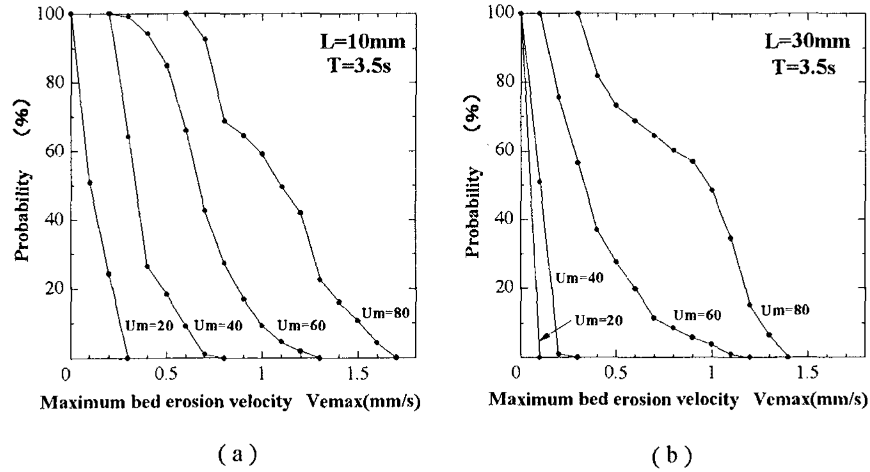


Fig.6 Probability of maximum bed erosion velocity occurring

(5) Moving Velocity of Bivalves on a Fixed Bed

We measured the velocity of moving bivalves which had been forced out into the water from the sand due to the flow, using a fixed bed with a smooth surface. Fig.7 shows a comparison between the experimental and theoretical results. The theoretical values were calculated by the following equation, and we regarded the behavior of bivalves as that of inanimate objects, which can not move by themselves.

$$M\frac{dUs}{dt}+C_m m\frac{d(Us-u)}{dt}=m\frac{du}{dt}+\frac{1}{2}C_D\rho_W A|u-Us|(u-Us)-\mu'(M-m)g\frac{Us}{|Us|}$$

Where, M is the mass of a bivalve, m is the mass of water equal to the volume of the bivalve, Us is the velocity of the moving bivalves and u is the water particle

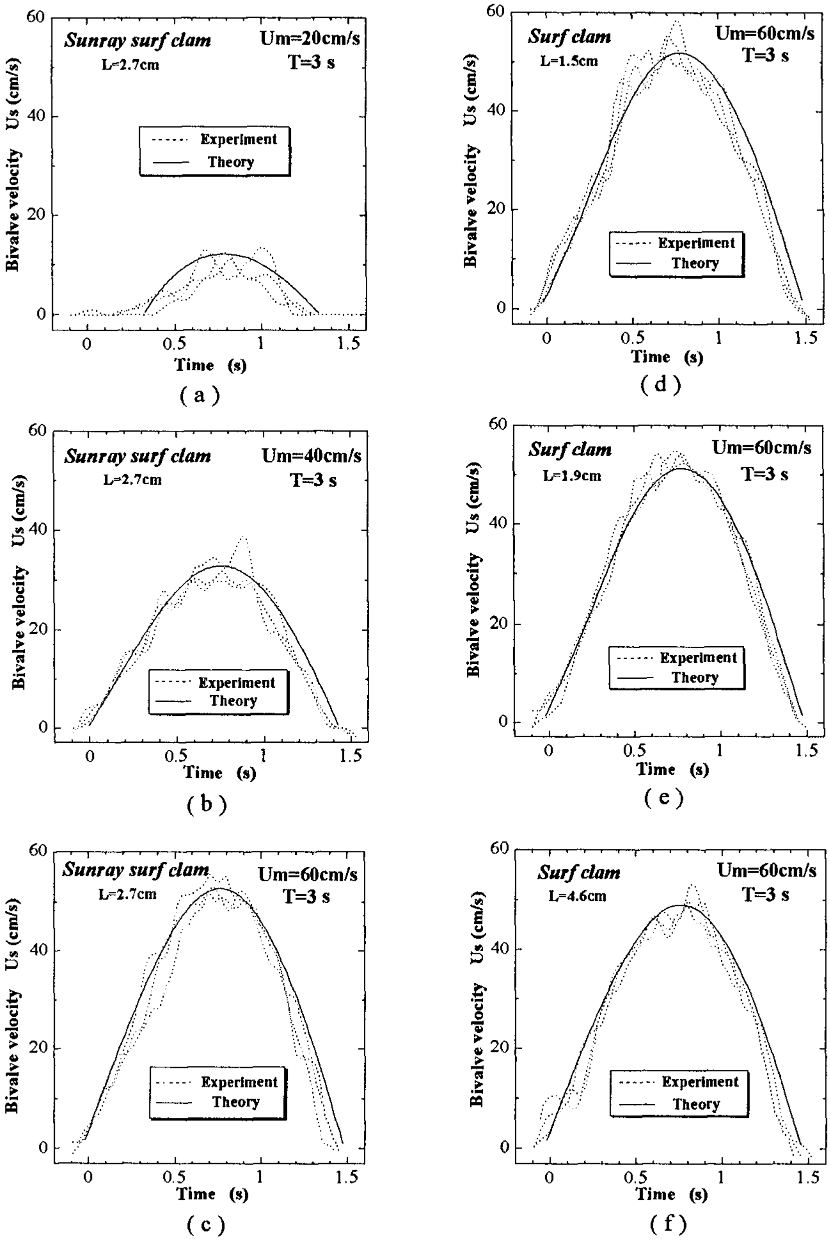


Fig.7 Moving velocity of the bivalves on a smooth surface fixed bed
(a)(b)(c) The case of using sunray surf clams at three different amplitude of the flow velocity
(d)(e)(f) The case of using surf clams of three different sizes

velocity. In the calculation, (1) the volume of a bivalve is converted into a globe and its projected area is regarded as the projected area A of the bivalve in the direction of the flow; (2) the drag coefficient $C_D = 1.0$; (3) the added mass coefficient $C_M = 0.5$; and (4) the coefficient of dynamic friction $\mu' = 0.1$. Fig.7(a), Fig.7(b) and Fig.7(c) show the results of experiments using sunray surf clams at three different amplitudes of the flow velocity. Fig.7(d), Fig.7(e) and Fig.7(f) show the results of experiments using surf clams of three different sizes.

The zero on the hour axis indicates the time when the main stream was reversed. The experimental values of three different velocities of moving bivalves in a one-half wave period were plotted. Turbulence was observed from experimental values because, while the flow acts on the bivalves, they turn around in various directions. However, in general, the theoretical values and experimental values agreed well.

Fig.7(a), Fig.7(b) and Fig.7(c) indicate that bivalves began moving at an early phase as the amplitude of the flow velocity became higher, and the ratio between the maximum value of the moving bivalves' velocity (Usm) and the amplitude of flow velocity (Um) approached 1.0. Fig.7(d), Fig.7(e) and Fig.7(f) indicate that the longer the shell length of the bivalves is, the lower Usm becomes, although there were few differences between shell lengths because of the high flow velocity.

The results of the present study showed that once bivalves are forced out into the water from the sand, there is little effect of their own movement. Therefore, they can be regarded as inanimate objects.

CONCLUSIONS

[1]The critical condition for which bivalves (surf clam) forced out of the sand and into the water by the water flow was determined by the ratio between Ve and Vb, which are the velocity of bed erosion and the burrowing rate of bivalves, respectively. Ve/Vb is approximately 1.1.

[2]The critical flow velocity at which bivalves can borrow into the sand increases as the burrowing rate rises.

[3]The burrowing rate of bivalves is related to both critical conditions, and the effects of the bivalves' own active movements (burrowing) were found to be significant for these conditions.

[4]The burrowing rate of bivalves below a certain water temperature is roughly proportional to the length of the shell, and decre ases with a fall in water temperature between 20℃ and 5℃.

[5]Under conditions where sand ripples are formed, as the amplitude of the flow velocity increases, the probability of a higher bed erosion velocity increases.

[6]The behavior of bivalves which are forced out of sand are hardly affected by their active movements, and they can be regarded as inanimate objects. Supposing that the volume of a bivalve is converted into a globe, the behavior of bivalves could be theoretically explained by setting C_D (drag coefficient) , C_M (added mass coefficient) and μ' (coefficient of dynamic friction) to 1.0, 0.5 and 0.1, respectively.

[7]The shorter the length of the bivalves, the lower the water temperature, and the

higher the wave height, the more easily the bivalves are forced out of the sand into the water by the water flow. These are considered to be one of the major factors affecting the mortality of young bivalves due to waves in winter.

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