SURF POINTS USING A SET OF STRUCTURES TO AMPLIFY SHIP GENERATED WAVES

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A method to obtain surfable waves by amplifying ship generated waves with both wave concentration structures and a reef is discussed to build surf points in calm areas of nearshore zones. The appropriate wave height for ordinary surfers is defined according to a questionnaire to local surfers in Kagoshima, Japan. The most effective shapes of the structures are determined on the basis of amplification factors of wave height through numerical calculation. We performed hydraulic experiments, as well as numerical computations, of ship generated waves amplified using the structures. Consequently, it is feasible to build a surf point in Kagoshima Bay by amplifying waves generated by the ferries through the proposed method with the structures which consist of the wave concentration structures and the reef.

Keywords: surfing; surfable wave; surf point; wave concentration structure; reef; ship generated wave

INTRODUCTION

Recently, several methods have been proposed to make rather high waves show adequate wave breaking types for surf riding (e.g. Nakano et al., 1994; West et al., 2003). These methods, however, are not applicable to calm areas in a bay or a lake. On the other hand, various ideas have been presented to generate surfable waves in artificial water pools (e.g. Schipper, 2007; Vries, 2007; Schmied et al., 2013). The objective of the present study is to build surf points at calm locations in the field by generating or amplifying waves for surfing. In this paper, we discuss a method to obtain surfable waves by amplifying ship generated waves with both wave concentration structures and a reef. First, the appropriate wave height for ordinary surfers is defined according to questionnaire data obtained from local surfers in Kagoshima, Japan. Second, the most effective shapes of the structures are determined on the basis of amplification factors of the maximum wave height through numerical calculation. Finally, we perform hydraulic experiments, as well as numerical computations, of ferry generated waves amplified using the structures which consist of the wave concentration structures and the reef to study feasibility of building a surf point in Kagoshima Bay.

SUITABLE WAVE HEIGHT FOR SURFING

Japanese surfers denote wave height using the size of parts of the body as shown in Fig. 1. A questionnaire has been carried out to 100 people, who periodically visit seven surf points in Kagoshima Prefecture, Japan, to evaluate suitable wave height for surfing. According to the results, the minimum wave height for surfing is “thigh” or “knee” for shortboarders, while “knee” or “shank” for both longboarders and bodyboarders; the minimum wave height for surfing is larger for beginners than that for experts. Therefore, the suitable wave height for general surfers is larger than 50 cm, which is the minimum wave height for beginners on shortboards.

NUMERICAL MODEL AND CALCULATION CONDITIONS

In the present paper, fluid motion is assumed to be irrotational and the velocity potential ϕ is expanded into a series as $\phi(\boldsymbol{x}, z, t) = \sum_{\alpha=0}^{N-1}(f_\alpha z^\alpha)$, resulting in the nonlinear wave equations derived by Kakinuma (2001) on the basis of a variational principle without any assumptions concerning wave nonlinearity and dispersion, i.e.,

$$\eta^\alpha \frac{\partial \eta}{\partial t} + \nabla\left\{\left(\eta^{\alpha+\beta+1} - b^{\alpha+\beta+1}\right)\nabla f_\beta\right\} - \frac{\alpha\beta}{\alpha+\beta-1}\left(\eta^{\alpha+\beta-1} - b^{\alpha+\beta-1}\right) f_\beta = 0, \qquad (1)$$

$$\eta^\beta \frac{\partial f_\beta}{\partial t} + \frac{1}{2}\eta^{\beta+\gamma}\nabla f_\beta \nabla f_\gamma + \frac{1}{2}\beta\gamma\eta^{\beta+\gamma-2} f_\beta f_\gamma + g\eta = 0, \qquad (2)$$

where $\eta(\boldsymbol{x},t)$ and $b(\boldsymbol{x})$ are water surface displacement and seabed level, respectively; the gravitational acceleration g equals 9.8 m/s^2.

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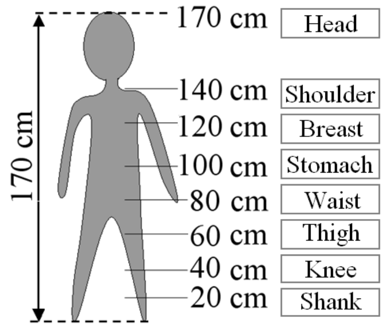


Figure 1. Definition of wave height by Japanese surfers using the size of body parts.

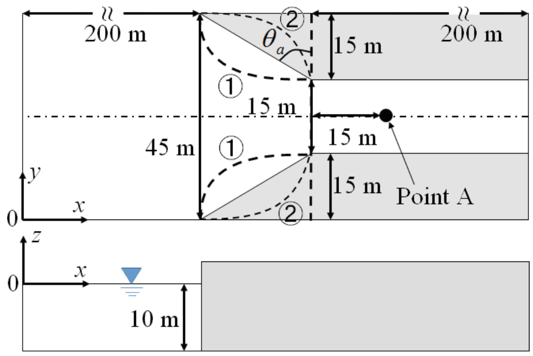


Figure 2. Wave concentration structures. The upper and lower figures show the plan and side views, respectively.

The fundamental equations are rewritten to finite difference equations, after which the time development is carried out in the two dimensions by applying implicit schemes similar to that of Nakayama and Kakinuma (2010) for internal waves. The number of terms for expanded velocity potential, N, is two to consider dispersion of waves. Assuming that the fluid is inviscid, the friction is neglected for simplicity. Note that wave breaking is not considered without a wave breaking model.

In numerical computation, ship generated waves are given as incident waves: the initial wavelength and period are $L_0 = 2\pi V_s^2/g \approx 15.6$ m and $T_0 = 2\pi V_s/g \approx 3.2$ s, respectively (Morita et al., 1995), where the dimensions of ship are as follows: the length is 56.1 m, the width is 13.5 m, and the draft is 2.8 m; the average cruise speed V_s is 4.94 m/s. Accordingly, the initial displacement of water surface is given by $\eta = a\{1+\cos(2\pi x/15)\}$ (0 m$\leqq x \leqq$7.5 m), where $a = 1.0$ m. The velocity potential $\phi(\boldsymbol{x},z,0)$ equals zero everywhere at the initial time.

WAVE CONCENTRATION STRUCTURES AND A REEF

In the present method, ship generated waves are amplified using both "wave concentration structures" as shown in Fig. 2 and an artificial "reef" sandwiched between the wave concentration structures as shown in Fig. 3 or Fig. 4 to obtain surfable waves. The most effective shapes of the structures with contraction angle of the wave concentration structures, θ_a, and front slope of the reef, θ_b, are evaluated through numerical computation. The still water depth is assumed to be uniformly 10 m.

Calculation results of amplification factors of the maximum wave height at Point A indicated in Fig. 2 are shown in Tab. 1 in case no reef is utilized. Note that the criterion wave height is the maximum wave height at Point A with no structure, where the wave height is evaluated through the zero-up-cross method. The table also shows the amplification factors of the maximum wave height in case the concentration structures ① and ② are utilized, where the front vertical surfaces are curved as the broken lines ① and ② in Fig. 2, respectively. According to Tab. 1, the amplification factor shows the maximum value when θ_a equals 45° or 60°.

Shown in Tabs. 2 and 3 are calculation results of amplification factors at Point B indicated in Figs. 3 and 4, respectively. In these cases, Reef A or Reef B is utilized with the wave concentration structures,

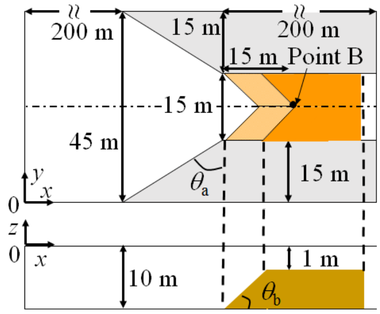


Figure 3. Wave concentration structures and Reef A.

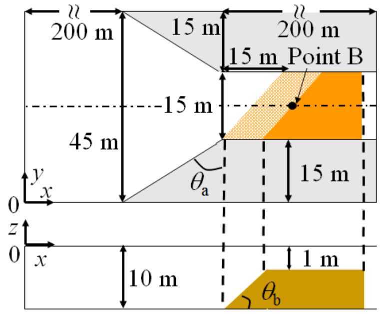


Figure 4. Wave concentration structures and Reef B.

Table 1. Amplification factors of wave height at Point A shown in Fig. 2 using the wave concentration structures.

θ_a	without structures	30°	45°	60°	70°	①	②
Maximum wave height (m)	0.55 Criterion value	0.67	0.71	0.72	0.67	0.66	0.59
Amplification factor of wave height	1.0	1.22	1.30	1.31	1.22	1.20	1.07

Table 2. Amplification factors of wave height at Point B shown in Fig. 3 using the wave concentration structures and Reef A.

θ_a	45°		60°		
θ_b	45°	60°	30°	45°	60°
Maximum wave height (m)	0.74	0.86	0.67	0.68	0.70
Amplification factor of wave height	1.35	1.56	1.23	1.24	1.27

Table 3. Amplification factors of wave height at Point B shown in Fig. 4 using the wave concentration structures and Reef B.

θ_a	45°			60°		
θ_b	30°	45°	60°	30°	45°	60°
Maximum wave height (m)	0.74	0.77	0.86	0.80	0.72	0.78
Amplification factor of wave height	1.35	1.40	1.56	1.45	1.31	1.42

the contraction angle θ_a of which is 45° or 60°. The criterion wave height is the maximum wave height at Point B without any structures. According to Tabs. 2 and 3, the most effective angles are as follows: $\theta_a = 45°$ and $\theta_b = 60°$.

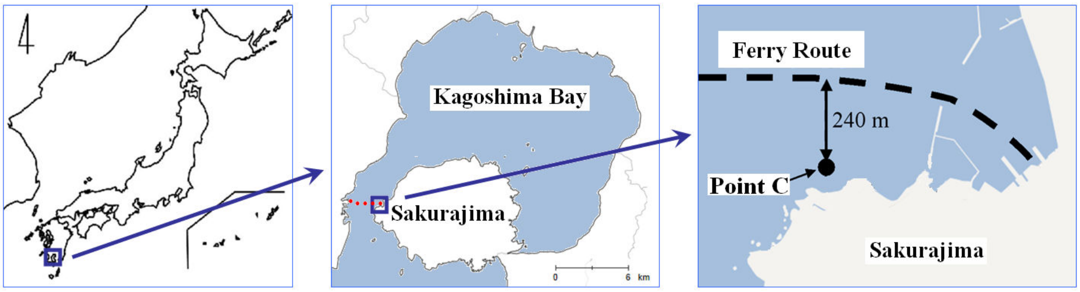


Figure 5. Representative route of Sakurajima Ferrys in Kagoshima Bay, Japan. Point C is the hypothetical site to set the proposed structures to amplify ferry generated waves.

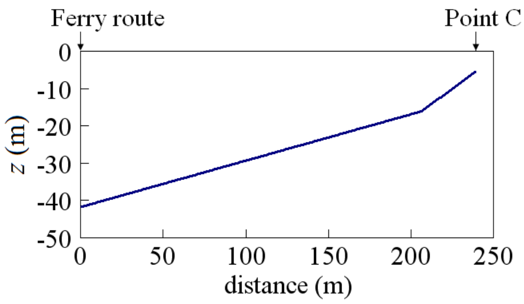


Figure 6. Distribution of still water depth along the shortest line between the ferry route and Point C shown in Fig. 5.

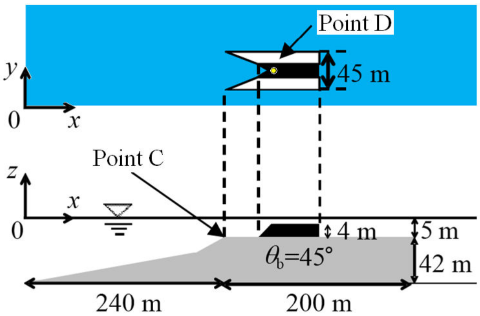


Figure 7. Seabed configuration and wave concentration structures with Reef A utilized in the numerical computation. The upper and lower figures show the plan and side views, respectively. The wave concentration structures are not drawn in the side view.

NUMERICAL SIMULATION OF SHIP GENERATED WAVES AMPLIFIED USING THE WAVE CONCENTRATION STRUCTURES AND REEF A

Both the wave concentration structures and Reef A or Reef B are supposed to be set up near a port in Kagoshima Bay, Japan, as shown in Fig. 5, to build a new surf spot by amplifying ferry generated waves. The hypothetical site to set the wave concentration structures and the reef is located at Point C indicated in Fig. 5, which also shows a representative route of Sakurajima Ferries. The distribution of still water depth along the shortest line between the ferry route and Point C is shown in Fig. 6, where the distance between them is about 240 m. The Sakurajima Ferry Line links the city center of Kagosima with Sakurajima in around 15 minutes every 10 or 60 minutes, 24 hours a day, 7 days a week. The dimensions and average cruise speed of Sakurajima Ferries are described above.

Figure 7 illustrates the wave concentration structures with Reef A utilized in numerical computation, where the wave concentration structures are not drawn in the side view. The contraction angle of the wave concentration structures, θ_a, is 60°, while the front slope of the reef, θ_b, is 45°; the width of the open mouth at Point C and the distance between the wave concentration structures are 45 m and 15 m, respectively. The still water depth is one meter over the crown of the reef.

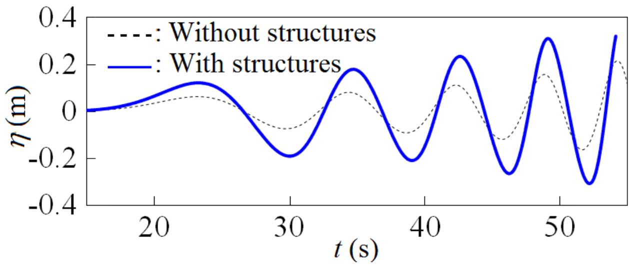


Figure 8. Numerical calculation results of water surface displacements at Point D shown in Fig. 7, in the cases with and without the wave concentration structures and Reef A.

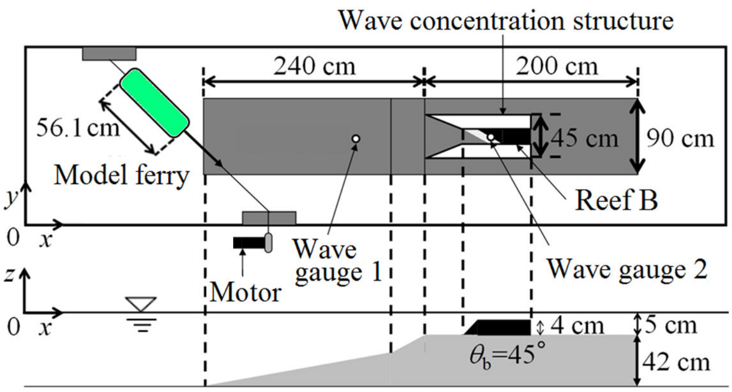


Figure 9. Schematic of laboratory setup. The scale of length is 1/100. The upper and lower figures show the plan and side views, respectively. The wave concentration structures are not drawn in the side view.

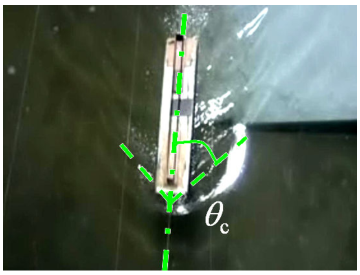
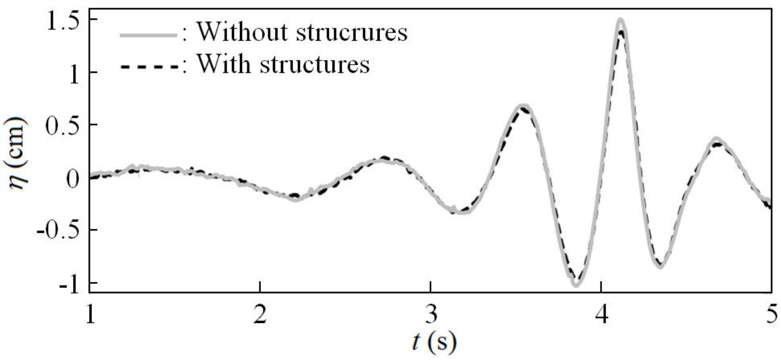


Figure 10. Model-ferry generated waves.

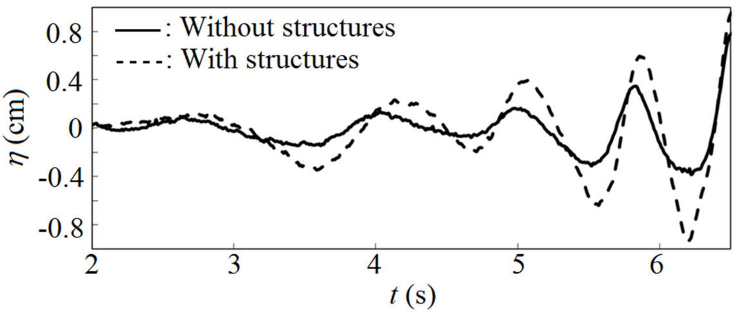
Numerical calculation results of water surface displacements at Point D indicated in Fig. 7 are shown in Fig. 8, where the calculation stopped when $t \approx 54$ s in case with structures because of "wave breaking" making the boundary condition become unsatisfied at the water surface. According to Fig. 8, the maximum wave height is about 0.6 m at the breaking point with the amplification factor of 1.53. Thus the wave breaking height is larger than 50 cm, i.e., the aforementioned minimum wave height for inexperienced shortboarders, such that it is possible to build a surf point using the set of structures to amplify ferry generated waves in the bay.

HYDRAULIC EXPERIMENTS OF SHIP GENERATED WAVES AMPLIFIED USING THE WAVE CONCENTRATION STRUCTURES AND REEF B

In hydraulic experiments, ship generated waves are actually obtained using a traveling model ferry. Illustrated in Fig. 9 is the schematic of laboratory setup including the wave concentration structures with Reef B, as well as the seabed configuration. The model ferry is pulled with a string by a motor, leading to ship generated waves as shown in Fig. 10. The contraction angle of the wave concentration structures, θ_a, is 60°, while the front slope of the reef, θ_b, is 45°; the width of the open mouth and the distance between the wave concentration structures are 45 cm and 15 cm, respectively. The still water



(a) Water surface displacements at the location of Wave gauge 1



(b) Water surface displacements at the location of Wave gauge 2

Figure 11. Experimental results of water surface displacements at the locations of two wave gauges shown in Fig. 9, in the cases with and without the wave concentration structures and Reef B.

depth is one centimeter over the crown of the reef. The navigation speed of model ferry is 1.0 m/s and the angle of the traveling direction of model ferry is 45°, which is the same as θ_c shown in Fig. 10 to amplify the ship generated waves effectively.

Two laser-type wave gauges are used to measure the water surface displacement especially over the crown of the reef, where the water depth is only around one centimeter. Aluminum powder is sprayed on the water surface as a reflector, for the infrared laser goes through the water surface.

Shown in Fig. 11 are experimental results of water surface displacements at the locations of Wave gauges 1 and 2 indicated in Fig. 9. Owing to the amplification with the amplification factor of about 1.73, the maximum wave height in the actual scale is around 1.9 m, which is larger than 50 cm, i.e., the minimum wave height for beginners to play surfing with a shortboard.

CONCLUSIONS

The method to obtain surfable waves by amplifying ship generated waves with both the wave concentration structures and the reef has been proposed to build surf points at calm locations in near-shore zones. The structures are utilized to increase the wave height in the present method, although coastal structures are usually used to decrease the wave energy.

According to the questionnaire to the local surfers in Kagoshima, the suitable wave height for general surfers is larger than 50 cm, which is the minimum wave height for inexperienced shortboarders.

The most effective shapes of the structures have been determined on the basis of the amplification factors of the maximum wave height through the numerical calculation as follows: the contraction angle of wave concentration structures is 45° and the front slope of reef is 60°.

We performed both the hydraulic experiments and numerical computations of the ship generated waves amplified using the structures. The wave breaking height was larger than the above-mentioned minimum wave height for inexperienced shortboarders in the present cases. Consequently, it is feasible to build a surf point in Kagoshima Bay by amplifying waves generated by the ferries through the proposed method with the structures which consist of the wave concentration structures and the reef.

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