CHAPTER 55

Variation of Surf Zone Turbulence in A Wave Period

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Abstract

The phase variation of turbulent intensity in the surf zone during one wave period is discussed. The existing data show a peak near the wave crest phase and a following gentle decrease. The peak delays downwards. The model by Deigaard et al.(1986) which uses the one equation model for the turbulent kinematic energy transportation explains the above mentioned trend roughly. The vertical convection term has no significant effect on the phase variation. The production term given by Deigaard et al. overestimates the energy production at the water surface by wave breaking.

Introduction

It is well known that the turbulence generated by wave breaking is responsible to the suspension of sediment in the surf zone. Also it determines the vertical profile of the undertow. At present, its time average over the wave period is important for practical purpose. To discuss these phenomena more in detail, however, we have to know its phase variation during one wave period.

In this study, the phase variation of the surf zone turbulence is discussed by using existing data. Then, the calculated results by using the existing analytical prediction techniques are compared with the data. Especially the application of the one equation model of

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the turbulent kinematic energy transportation is discussed.

Experimental Data on Phase Variation

Stive(1980) published his data on the turbulent intensity in a surf zone on a uniform slope beach in a wave tank. The experimental conditions are shown in Table 1. The breaking water depth h_b was about 26cm. He presented the results in several figures. Fig.1 is an enlarged copy of one of his figures. The mean water depth d at the measuring point was 18.6cm. The abscissa shows the wave phase. The ordinate shows a non-dimensional height above the mean water level. The curves are the contour lines of turbulent intensity. It is clear that the turbulent intensity is large under the wave crest.

Table 1 : Experimental Conditions

	Stive(1980) test 2	Sakai et al.(1982) case H2
i	1/40	1/28
T(sec)	3.0	1.16
H_o(cm)	14.2	
h_b	26.0	17.7
H_b	22.6	12.8
H_o/L_o	0.010	0.066

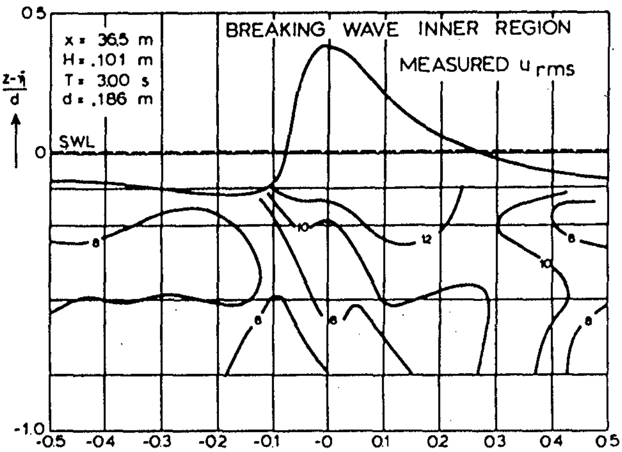

Fig.1 Experimental result by Stive(1980) (d = 18.6cm)

To make clear the phase variation of the turbulent intensity, its values were read from his figure at several levels, and plotted in a usual phase-intensity figure. Fig.2 shows the result at d = 14.3cm. z is a vertical coordinate and positive upwards. The origin is at the still water.

As seen in the curve at z = -2.4cm, the profile of phase variation of turbulent intensity is similar to that of the water level. It has a peak near the wave crest phase. At z = -4.7cm, this trend still exists. At z = -7.4cm, the trend is not so clear. At least at the upper two levels there is a peak and then a gradual decrease follows. One interesting fact is that the phase of the peak delays downwards. In the case of 18.6cm water depth(Fig.1) the same trend is seen. The peak under the

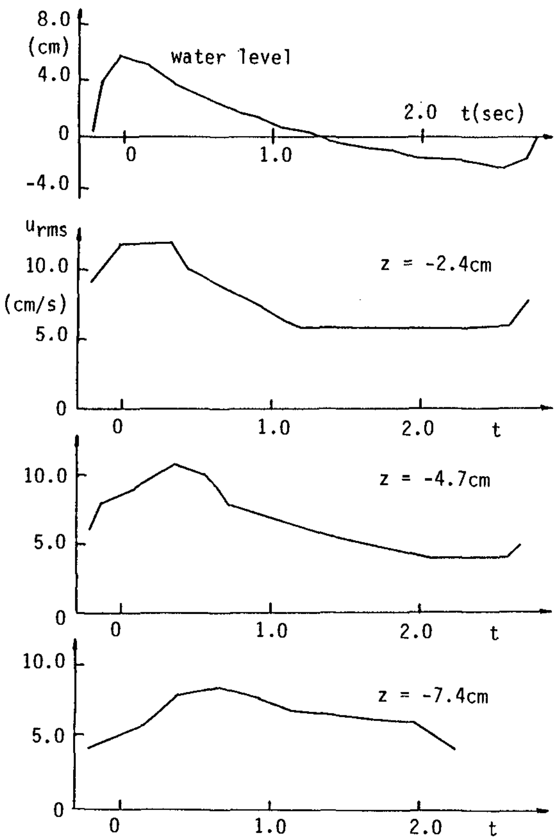

Fig.2 Phase variation of turbulent intensity (Stive, 1980, test 2, d = 14.3cm)

wave crest and the following gradual decrease are seen. The peak phase delays downwards.

To examine whether or not other data show the similar trend, other data are checked. One of the authors measured the turbulent intensity in a surf zone in a wave tank(Sakai, Inada and Sandanbata, 1982). The experimental conditions are shown in Table 1, and compared with Stive's conditions. Fig.3 is one example of the results. The still water depth h was 12.3cm. The similar trend is found. The data of Nadaoka(1986) shows a long tail of the contour lines. This also means the downward delay of the peak phase.

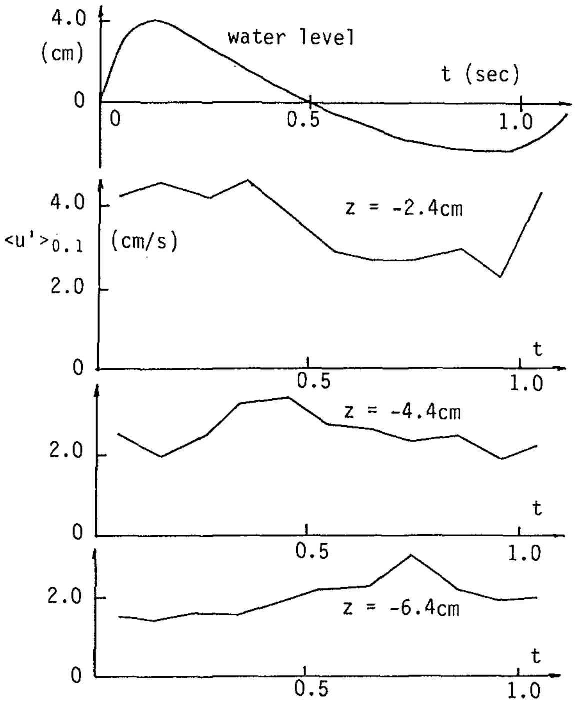

Fig.3 Phase variation of tubulent intensity (Sakai, et al., 1982, case H2, h = 12.3cm)

Models on Phase Variation

Deigaard et al.(1986) applied the one equation model for the turbulent kinematic energy transportation to simulate the phase variation of turbulent intensity during one wave period in a surf zone. The equation which they used is given as follows :

$$\frac{\partial k}{\partial t} = \frac{\partial}{\partial y}\left(\frac{\varepsilon}{\sigma_k}\frac{\partial k}{\partial y}\right) + \frac{\text{PROD}}{\rho} - c_d\frac{k^{3/2}}{l} \quad , \qquad (1)$$

where k is the turbulent kinematic energy, y is the vertical coordinate directed upwards from bottom, ε is the turbulent eddy viscosity given by $l\sqrt{k}$, l is the lenth scale of turbulence, $\sigma_k = 1.0$, ρ is the density of water and $c_d = 0.08$.

Eq.(1) is a simplified equaiton of one equation model for the turbulent kinematic energy transportation. The three terms in the right hand side represent the diffusion of turbulent kinematic energy by the tubulence itself, the producton of it and the dissipation. They thought that the turbulence energy is generated at the water surface, diffused downwards by itself and dissipated.

The production of turbulent energy at the water surface is given by

$$\text{PROD} = E_{loss}\frac{36}{(H\beta T)^2}z\left(1-\frac{z}{H}\right)t\left(1-\frac{t}{\beta T}\right)$$

$$: 0 \le z \le H, \;\; 0 \le t \le \beta T \qquad (2)$$

$$E_{loss} = \frac{H^3}{(4D^2 - H^2)}\gamma D \;, \quad \beta = 2\frac{D + H/2}{L} \;,$$

where H is the wave height, D is the mean water depth, γ is the unit weight of water, L is the wave length, T is the wave period and z is the vertical coordinate directed downwards with its origin at the surface. This expression is based on experimental data of a hydraulic jump.

They calculated the phase variation of turbulent intensity for the conditions of the experiment by Stive. They presented the calculated result in the similar manner as Stive did(Fig.1).

The values are read from their figures, and compared with the experimental result by Stive. Fig.4 is the case of 18.6cm water depth. The experimental result is shown with thick full line. The calculated result by Deigaard et al. is shown with chain line. It explains the experimental result roughly.

The dotted line is the calculated result by using a model of one of the authors(Sakai et al., 1982). The broken line is the calculated result by using a model of

Svendsen(1987). The model of Sakai et al. also explains the experimental result roughly. In the model of Svendsen, the production and diffusion terms were neglected. So this model explains only the gradual decrease. Although the model of Sakai et al. explains the experimental result as roughly as the model of Deigaard et al., the model of Deigaard et al. is most suitable physically.

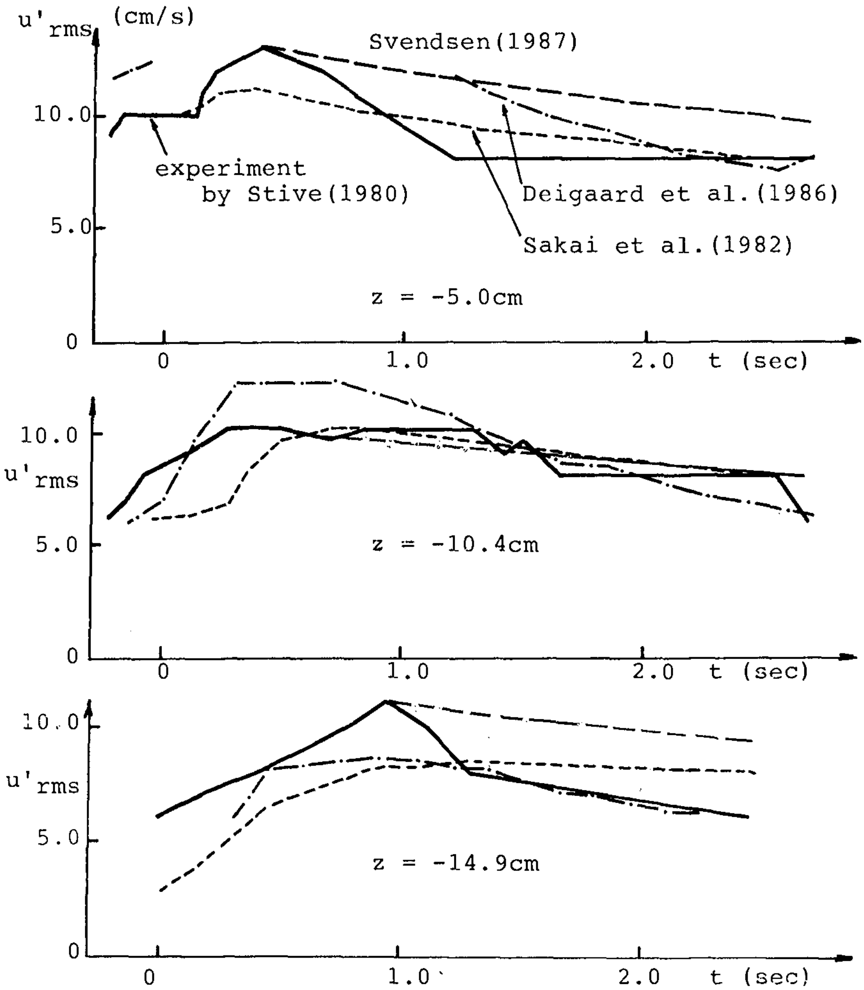

Fig.4 Comparison of predicted results with experimental result(Stive, test 2, d = 18.6cm)

Convection Terms

Svendsen(1987) compared the vertical distribution of mean turbulent intensity of Stive's experiment with that of Deigaard et al.(Fig.5). The calculated vertical distribution by Deigaard et al.is steeper than that of the experimental result by Stive. Svendsen thought that this was due to the neglection of the convection term in the turbulent kinematic enery transportation equation.

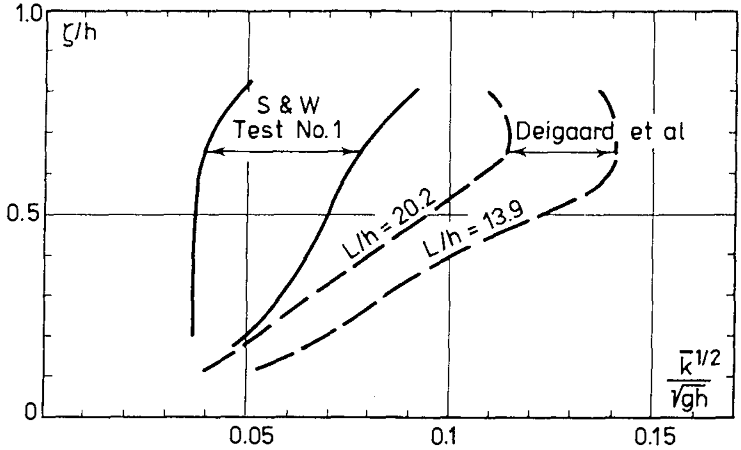

Fig.5 Comparison of predicted mean turbulent intensity (Deigaard et al., 1986) with experimental data (Stive, 1980) (Svendsen, 1987, Fig.9)

$$\frac{\partial k}{\partial t} + u\frac{\partial k}{\partial x} + v\frac{\partial k}{\partial y} = \frac{\partial}{\partial x}(\frac{\varepsilon}{\sigma_k}\frac{\partial k}{\partial x}) + \frac{\partial}{\partial y}(\frac{\varepsilon}{\sigma_k}\frac{\partial k}{\partial y}) + \frac{\text{PROD}}{\rho} - c_d\frac{k^{3/2}}{l} \tag{3}$$

Eq.(3) is the full equation of the one equation model for the turbulent kinematic enery tansportation. This equation was originally developed for the two-dimensional boundary layer flow. The second and third terms in the left hand side are the convection terms. The first and second terms in the right hand side are the horizontal and vertical diffusion terms respectively. Deigaard et al. neglected the convection terms and the horizontal diffusion term. From the data by Stive, the magnitude of the vertical diffusion term was estimated. It was found that the magnitude of the vertical convection term might be same order as that of diffusion term.

To check the effect of the convection terms, a similar calculation to that by Deigaard et al. is done. Fig.6 shows the discretization of the wave phase and the hight above the bed for the case of d = 18.6cm of Stive's experiment. The i' and j' values indicate the discretization of the phase and the height above the bed. Only the vertical convection term is included. In Stive's paper, there was no data on the vertical water particle velocity. It was assumed, therefore, that the velocity field is similar in the surf zone. The vertical water particle velocity was calculated from other data(Nadaoka, 1986).

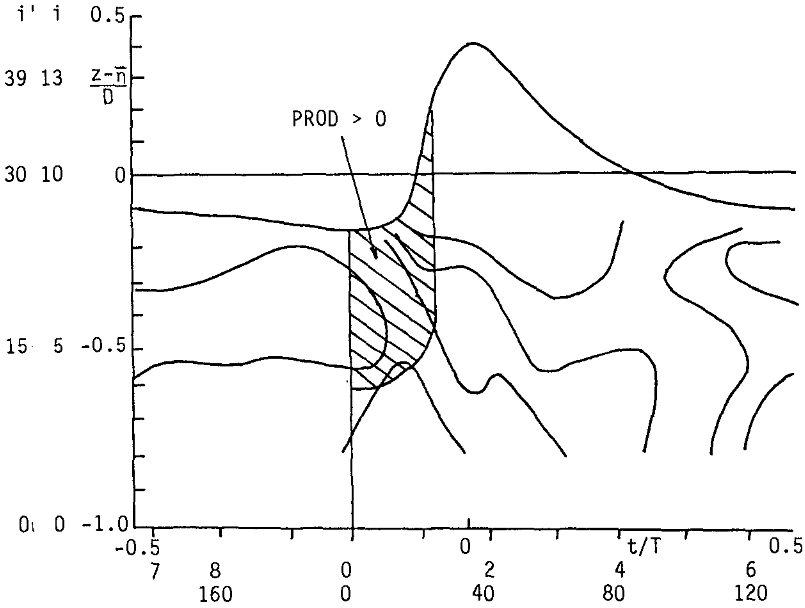

Fig.6 Discretization of wave phase and hight above bed for case of d = 18.6cm of Stive's experiment

The dotted line in Fig.7 is the calculated result in which the vertical convection term is included for the case of d = 18.6cm of Stive's experiment. The production and dissipation terms are multiplied by 0.3 and 0.5 respectively(explained later). The full line is the calculated result without the convection terms. The cross points are the measured result by Stive. There is no significant improvement on the calculated result.

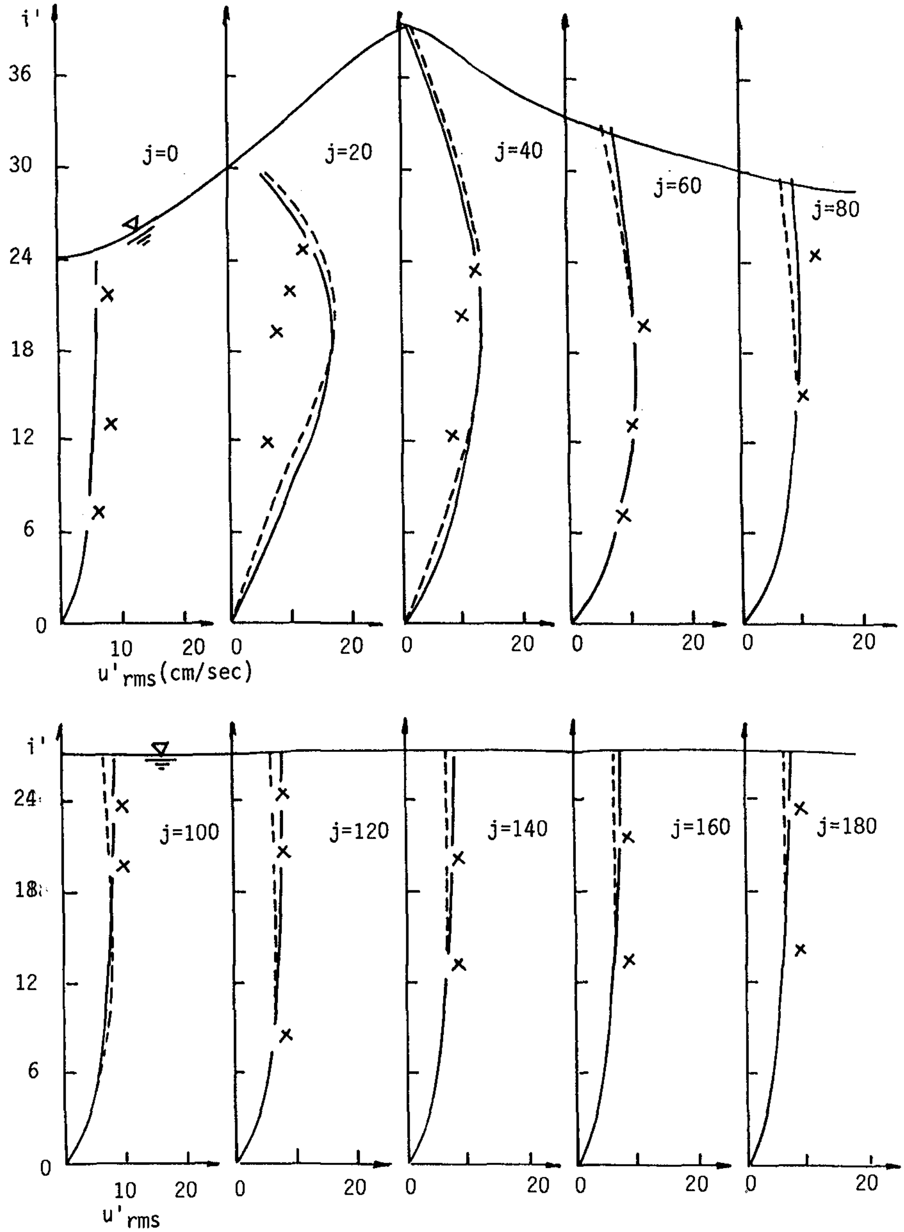

Fig.7 Effect of vertical convection term on phase variation of turbulent intensity

Production Term

Then the production term was also estimated from the data by Stive. It was found that the production term was predominant at least under the wave crest. The production of turbulent energy is expressed by Eq.(4). It is a product of the Reynolds stress and the vorticity.

$$-\overline{u'_\alpha u'_\beta}\left(\frac{\partial U_\alpha}{\partial x_\beta}\right) \approx -\overline{u'v'}\frac{\partial U}{\partial y} \approx \overline{u'v'}\left(\frac{\partial V}{\partial x}-\frac{\partial U}{\partial y}\right) \qquad (4)$$

In the 20th Conference on Coastal Engineering, one of the authors presented a numerical simulation of the motion after wave breaking on a beach(Sakai et al., 1986)(Fig.8).

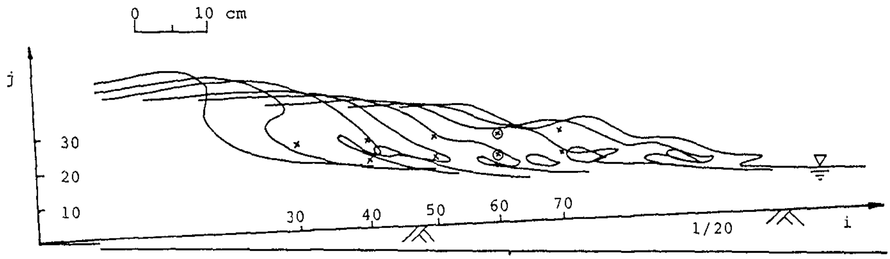

Fig.8 Numerical simulation of motion after wave breaking on beach (Sakai et al., 1986)

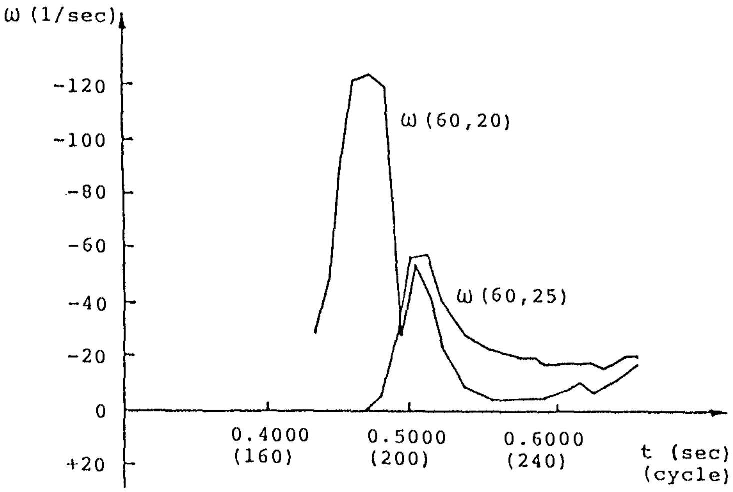

Fig.9 Time variation of vorticity (Sakai et al., 1986)

The vorticity was estimated from the simulation result at two points indicated by the circled cross point. Fig.9 is the time variation of vorticity.

The vorticity increases and decreases very rapidly. The time interval is about 0.1sec. In the model of Deigaard et al., the time interval of the production term is given by βT in Eq.(2). The calculated value of βT for the simulated case is about 0.3sec. The Deigaard et al.s' model may overestimate the time interval of the production term.

To check the effect of the production term, a similar calculation to that by Deigaard et al. is done. In this case, the discretization of the phase and the height above the bed is rather rough as indicated by the i and j values in Fig.6. The full curves in Fig.10 show the result when the Deigaard et al.s' equaiton is used for the case of d = 18.6cm of Stive's experiment..

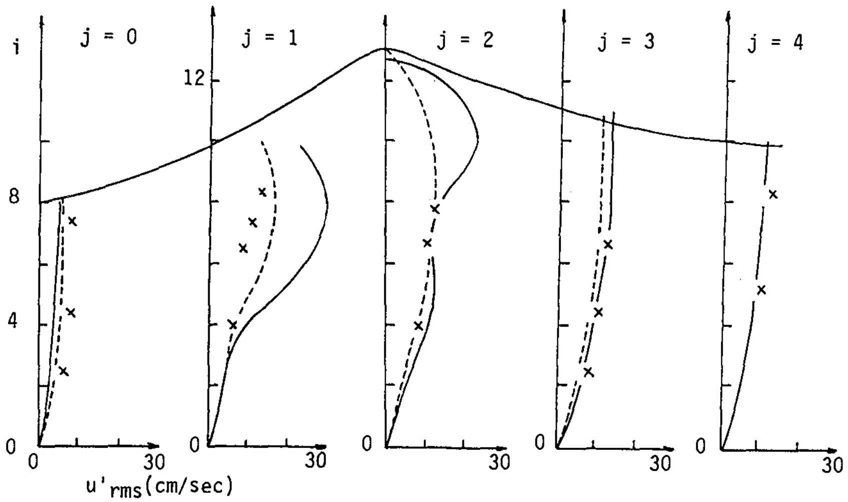

Fig.10 Effect of production term on phase variation of turbulent intensity

The calculated result overestimates the turbulent intensity under the wave crcst. Then, the production term was multiplied by 0.3. And the dissipation term was multiplied by 0.5. The calculated value decreases as indicated by the dotted curves. This means that the production given by Deigaard et al. is too large, and its 30% is enough to reproduce the measured result.

In fact, from a personal communication with Deigaard, it was found that he himself did a similar correction in his calculation. The production term is strongly related to the slope of the vertical distribution of turbulent intensity(Fig.5). The correct estimation of the production is, therefore, necessary to improve the prediction.

The reason for the reduction of the dissipation remains unclear.

Conclusions

(1) The existing data on the phase variation of turbulent intensity in surf zone during one wave period show a peak near the wave crest and a following gentle decrease. The phase of the peak delays downwards.

(2) The model of Deigaard et al.(1986) which utilized the one equation model for the turbulent kinematic energy transportation, explains the experimental results roughly.

(3) The vertical convection term in the turbulent kinematic energy transportation equation has no siginificant effect on the variation.

(4) The production term of Deigaard et al. gives a longer time interval than the vorticity in a numerical simulation of motion after wave breaking by Sakai et al.(1986).

The production term of Deigaard et al. gives a steeper slope of the vertical mean turbulnent intensity distribution than the existing experimental results.

The production multipled by 0.3 and the dissipation multiplied by 0.5 gives a reasonable result.

It is necessary to refine the production term to predict more accurately the phase variation of turbulent intensity during one wave period in the surf zone.

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