ARCHIWUM HYDROTECHNIKI
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Dynamics of wave–current bottom boundary layer Part 2 Modelling turbulent boundary layer in nonlinear wave and current motion

1. Introduction

This article is a closure of the series of papers i.e. Kaczmarek & Ostrowski (1989), Kaczmarek (1990), Kaczmarek & Ostrowski (1991), Kaczmarek & Szmytkiewicz (1991) and Kaczmarek & Ostrowski (1992). The main purpose of these works has been to provide a relatively simple mathematical tool ensuring the prediction of velocity and friction (instantaneous and mean values) inside the boundary layer with nonlinear (asymmetric) wave and the effects associated with the nonlinear interaction of waves and currents. The theoretical treatment of this paper is restricted to the two–dimensional flow, with wave propagation either 0^o or 180^o versus steady current.

The interaction of current and nonlinear waves is of utmost importance from an engineering point of view. It is characteristic for a coastal zone in the region behind and ahead of surf line because of the balance of wave asymmetry. Inter alia, it is possible that a time–averaged flow is offshore in the entire outer region while in the boundary layer, due to wave asymmetry, the reverse i.e. onshore mean current exists.

As in Part 1, the problem of waves and currents interaction will be dealt with in two regions — potential oscillatory flow with superimposed current and a boundary layer, with the continuity laws satisfied at the interface of the two regions. The solution in the boundary layer is conditioned by the knowledge of the flow in the outer region.

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The Authors presented a concept of the theoretical solution for a boundary layer due to sinusoidal wave and current (Kaczmarek & Ostrowski 1991). It has been shown that although a current and a wave motion can be described by separate equations, the effect of nonlinear interaction between waves and a current is incorporated in the eddy viscosity, thus modelling of the turbulent viscosity ν_t. Two different cases have been discussed. In the first case, turbulence is generated within the boundary layer, and the logarithmic mean velocity distribution holds in the outer region:

$$U_c(z) = \frac{u_{fc}}{\kappa} ln \frac{30z}{k_w} \tag{1}$$

while the eddy viscosity coefficient ν_{tc} is given by the following relationship:

$$\nu_{tc} = \kappa u_{fc} z \tag{2}$$

The apparent roughness k_w incorporates the influence of the waves on the current. For coupled motion of waves and current, a larger resistance is felt by the current outside the wave boundary layer than when no waves are present. This increased resistance manifests itself as an apparent roughness larger than the physical roughness. Thus the apparent roughness k_w, mean friction velocity u_{fc} at the bed create the mean velocity distribution $U_c(z)$ outside the boundary layer.

The second case encompasses a system of the interaction where the turbulence in a basic region of the flow (outside the boundary layer) is created by external events, such as wave breaking in the surf zone. For this case the Authors, postulating the continuity of velocity and shear stress inside the turbulent boundary layer, have worked out an iterative scheme ensuring the determination of mean velocity at the top of this layer (slip velocity), coupled with undertow in the breaker zone.

It has been shown that the slip velocity obtained by the above procedure does not differ much from that which would exist if an assumption was made of zero shear stress at the top of boundary layer. Thus the mean velocity distributions inside the turbulent boundary-layer and outside this layer are practically uncoupled.

Considering the outer region, in which the turbulence is generated by a wave breaking, one should admit that the eddy viscosity ν_{tc} in this region of flow is not fully recognized yet. The discussion of the exchange of energy in spilling breakers and broken waves (Deigaard & Fredsoe 1989) leads us to the determination ν_{tc}. Possessing the theoretical formula of ν_{tc} we may provide more precise mathematical description of undertow. Basing on the continuity of velocity and friction the limit of boundary layer we modify the iterative scheme enabling the determination of the slip velocity at the top of this layer. This modification of the scheme, given in Kaczmarek & Ostrowski (1991), it provides greater efficiency and effectiveness of the computations.

Two steps have been proposed:

- Step I — an iterative scheme providing the slip velocity
- Step II — a procedure yielding instantaneous and time–averaged velocity distributions in the boundary layer due to wave asymmetry.

The results of computations of undertow have been compared with experimental tests of Stive & Wind (1986) and Buhr-Hansen & Svendsen (1984), Section 2. The comparisons have been made between computed velocity profiles in the wave-current boundary layer and available laboratory data by Hwung & Lin (1990).

2. Undertow combined with a bottom boundary layer

The vertical distribution of the undertow velocity $U_c(z)$ may be estimated by the following formula, cf. Svendsen (1984):

$$U_c(z) = \frac{1}{2}\frac{1}{\nu_{tc}}\frac{dR}{dx}(z+h)^2 + \left[2\frac{(U_m - V)}{d_{tr}} - \frac{1}{3}\frac{d_{tr}}{\nu_{tc}}\frac{dR}{dx}\right](z+h) + V \tag{3}$$

with the coordinate system beginning at mean water level and z axis directed upwards.

In Eq. (3) d_{tr} denotes the distance between sea bottom and wave trough, V is the slip velocity, $R \equiv g\overline{\zeta} + \left(\overline{\tilde{U}^2} - \overline{\tilde{W}^2}\right)$, $\overline{\zeta}$ is the mean water surface elevation and $\tilde{U}$, $\tilde{W}$ are the oscillatory velocities.

The eddy viscosity ν_{tc} in outer region is assumed vertically constant. As shown by Svendsen (1984) the inclusion of a conceptually realistic depth-variation of ν_{tc} has the effects of a secondary importance when compared to the effects of incorporating alternative boundary conditions at the bottom.

Equation (3) is obtained with the boundary conditions specifying that the total mean mass flux below the wave trough level should balance that above this level, implying that:

$$U_m d_{tr} = \int_{-h}^{\zeta_{tr}} U_c(z)dz \equiv -\int_{\zeta_{tr}}^{\zeta_{cr}} U_c(z)dz \tag{4}$$

and there is a slip velocity V at the upper limit of the boundary layer.

However, the slip velocity V is unknown and that is the reason for involving the iterative procedure in the solution proposed by Kaczmarek & Ostrowski (1991). In this procedure the continuity of velocity and the shear stress at the top of a boundary layer is required. The quantity ν_{tc} should be given explicitly to evaluate the shear stress in the outer region to be matched with the friction at the upper limit of the bottom boundary layer.

There has been a lack of a precise formula for ν_{tc} till now and the existing attempts of estimation for eddy viscosity coefficient are based, for example, on the similarity between the flow in wakes and that in quasi-steady breaking waves, as proposed by Stive & Wind (1986). Within the computations of Kaczmarek & Ostrowski (1991) the choice of ν_{tc} value has followed the quantities given by Stive & Wind (1986) and Buhr-Hansen & Svendsen (1984) evaluated from their experiments.

It can be assumed that an eventual small energy loss in the wave boundary layer may be neglected because the dissipation of energy in spilling breakers and broken waves mainly occurs in the region of the surface roller and close to it. Thus the rate of total mean work done by the shear stress which is extracted from the outer mean flow – undertow – and converted to turbulence must be of the same order as the small energy loss in a wave boundary layer. Adapting the result (33) from Part 1 (Kaczmarek & Ostrowski 1992) it is found that:

$$\int_0^{\zeta_{tr}} \overline{\tau} \frac{dU_c}{dz} dz = O(\rho \overline{\tilde{U} u_f |u_f|}) \tag{5}$$

The shear stress at a trough level is given by the following relationship:

$$\frac{1}{\rho} \overline{\tau}(\zeta_{tr}) = d_{tr} \frac{dR}{dx} \tag{6}$$

Equation (6) is obtained by an adaptation of the result of computations presented in Kaczmarek & Ostrowski (1991) confirmed by experimental observations of Stive & Wind (1986) and Buhr–Hansen & Svendsen (1984) that the mean bottom shear stress in a two–dimensional surf zone is negligibly small.

It seems to be worth using the obtained formula (5) for theoretical estimation of ν_{tc}. From Eq. (5) one has:

$$\overline{\tau}(\zeta_{tr}) \left[U_c(\zeta_{tr}) - U_m \right] = O(\rho \overline{\tilde{U} u_f |u_f|}) \tag{7}$$

and next, on the strength of Eq. (3) and the simplified formula of slip velocity (Eq. 47 in Kaczmarek & Ostrowski 1991):

$$\left(\frac{dR}{dx} \right)^2 \frac{1}{\nu_{tc}} \frac{1}{3} d_{tr}^3 \approx \overline{\tilde{U} u_f |u_f|} \tag{8}$$

from which:

$$\nu_{tc} = \frac{\frac{1}{3} \left(\frac{dR}{dx} \right)^2 d_{tr}^3}{\overline{\tilde{U} u_f |u_f|}} \tag{9}$$

In order to check the obtained theoretical formula (26) the authors repeated the calculations of undertow for the parameters of experimental tests of Stive & Wind (1986) and Buhr–Hansen & Svendsen (1984), see Tab. 1 in Kaczmarek & Ostrowski (1991). The results of computations with the use of present formula (solid line) and with ν_{tc} estimations from experimental data (dashed line) in comparison to laboratory measurements (dots) are shown in Figs. 1 and 2.

It is visible that Eq. (9) seems to be a good theoretical option for predicting the undertow distribution.

For the computations the modified version of iterative procedure presented in Kaczmarek & Ostrowski (1991) has been used. The modification bases on the fact that the equation of motion for the case of linear wave and current may be solved separately with separate boundary conditions. As it was pointed out by Kaczmarek & Ostrowski (1991) the assumption of time–independence of eddy viscosity ν_t in the boundary layer allows one to treat the combined wave and current motion by separate equations.

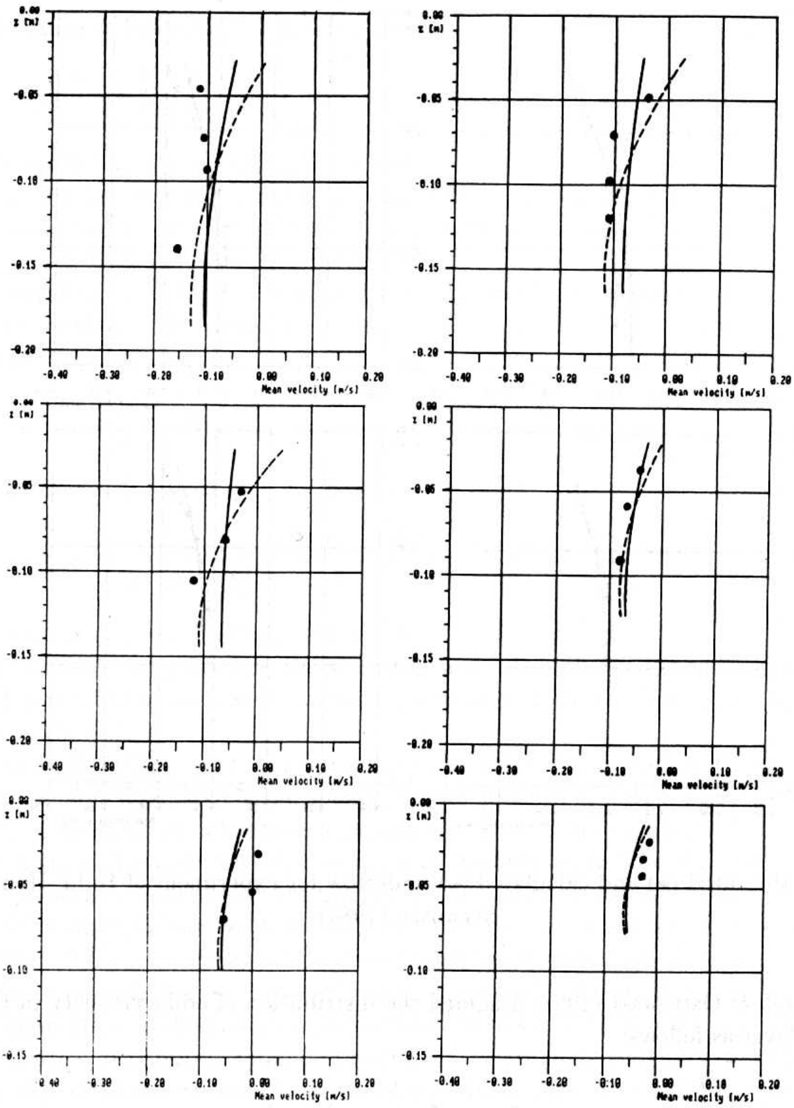


Fig. 1. Measured (•) and calculated (–) undertow for experiment of Stive & Wind (1986)

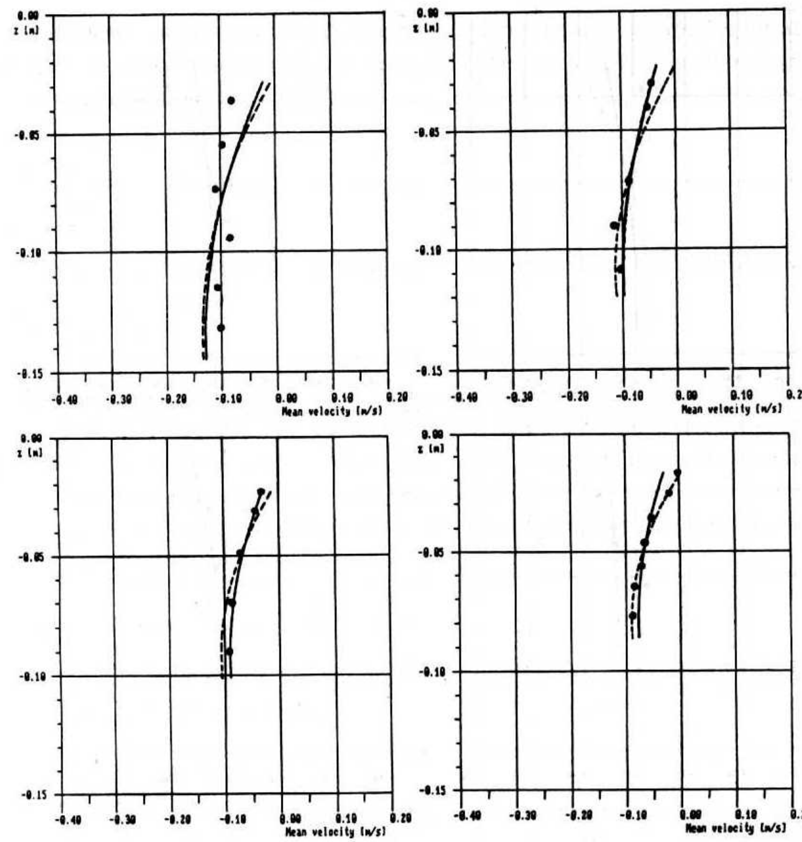


Fig. 2. Measured (•) and calculated (–) undertow for experiment of Buhr–Hansen & Svendsen (1984)

Kaczmarek & Ostrowski (1991) assumed the distribution of eddy viscosity in the boundary layer as follows:

$$\begin{aligned} \nu_t(z) &= \kappa \hat{u}_f z & \text{for} \quad & \tfrac{k_s}{30} \le z \le \tfrac{\delta_m}{4} + \tfrac{k_s}{30} \\ \nu_t(z) &= \kappa \hat{u}_f \left(\tfrac{\delta_m}{4} + \tfrac{k_s}{30}\right) & \text{for} \quad & z > \tfrac{\delta_m}{4} + \tfrac{k_s}{30} \end{aligned} \tag{10}$$

where k_s is Nikuradse roughness parameter, $\kappa = 0.4$ is von Karman constant, $\hat{u}_f$ is an equivalent friction velocity and δ_m is an equivalent boundary layer thickness.

Thus the determination of instantaneous velocities $u(z,t)$ may be the sum of the solution of equation of motion for wave only with the oscillatory velocity at the top of boundary layer as a boundary condition and the current described by equations:

$$\kappa \hat{u}_f z \frac{\partial u_c}{\partial z} = u_{fc}|u_{fc}| \tag{11}$$

for the range $< k_s/30; \delta_m/4 + k_s/30 >$ and

$$\kappa \hat{u}_f \left(\frac{\delta_m}{4} + \frac{k_s}{30} \right) \frac{\partial u_c}{\partial z} = u_{fc}|u_{fc}| \tag{12}$$

for the range $(\delta_m/4 + k_s/30; \delta_m/2 + k_s/30 >$.

The friction velocity $u_f(\omega t)$, the boundary layer thickness $\delta(\omega t)$ and the root time-mean square friction velocity u_{fc} are determined from the solution of integral equation, cf. Kaczmarek & Ostrowski (1991).

Integrating Eqs. (11), (12) and taking advantage of the condition $u_c(z = k_s/30) = 0$ and the condition of continuity of u_c at $z = \delta_m/4 + k_s/30$ one comes up with the formulas:

$$u_c(z) = \frac{u_{fc}|u_{fc}|}{\kappa \hat{u}_f} ln \frac{z}{\frac{k_s}{30}} \tag{13}$$

for the range $< k_s/30; \delta_m/4 + k_s/30 >$ and

$$u_c(z) = \frac{u_{fc}|u_{fc}|}{\kappa \hat{u}_f \left(\frac{\delta_m}{4} + \frac{k_s}{30} \right)} \left(z - \frac{\delta_m}{4} - \frac{k_s}{30} \right) + \frac{u_{fc}|u_{fc}|}{\kappa \hat{u}_f} ln \frac{\frac{\delta_m}{4} + \frac{k_s}{30}}{\frac{k_s}{30}} \tag{14}$$

for the range $(\delta_m/4 + k_s/30; \delta_m/2 + k_s/30 >$.

In the proposed procedure the sought value of slip velocity in the outer region has been fitted to the mean velocity at the upper limit of boundary layer ($z = 2\delta_m + k_s/30$) given by Eq. (14).

It is worthwhile to note that at the top of boundary layer the term $\overline{Uw_\infty}$ associated with the energy dissipated in the boundary layer possesses a certain value. Although the neglect of the dissipation has been assumed, it is interesting to evaluate the contribution of this term to the undertow distribution near the bottom. In order to do that the $\overline{Uw_\infty}$ term has been estimated with the use of Eq. (29) in Part 1 and involved in the iterative scheme by superposition with the undertow shear stress at the top of boundary layer. The effect of $\overline{Uw_\infty}$ on the undertow distribution has been evaluated for one of the cases of Buhr-Hansen & Svendsen's (1984) experiment and is depicted in Fig. 3 (solid line) with comparison to the undertow profile without this effect (dashed line). Additionally the undertow distribution computed with the assumption of zero undertow shear stress at the top of boundary layer is given (dotted line). As one could have expected the contribution of $\overline{Uw_\infty}$ is very small and the proposed formula for slip velocity (47) in Kaczmarek & Ostrowski (1991) obtained with the assumption of zero undertow shear stress at the bottom is sufficient for practical engineering purposes.

3. Velocity and shear stress in boundary layer due to nonlinear wave and current

3.1. Theoretical basis of present model

The model encompasses two stages of solution. Within the first stage an interaction of the sinusoidal wave and the steady current is considered. The iterative procedure

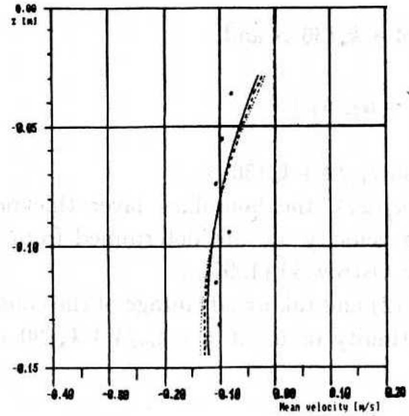


Fig. 3. The $\overline{Uw_\infty}$ contribution to undertow profile

to obtain the current friction velocity u_{f0} is employed (as described in Kaczmarek & Ostrowski 1991).

Within the second stage, the time–distribution of total friction velocity u_f must be determined. The equation of motion (6) from Part 1 after integration over the thickness of a boundary layer reads:

$$\frac{\tau(\delta)}{\rho} - \frac{\tau_0}{\rho} = - \int_{\frac{k_s}{30}}^{\delta + \frac{k_s}{30}} \frac{\partial}{\partial t}(U - u) dz \tag{15}$$

in which:

$$\tau(\delta) = -\rho u_{f0}^2 \tag{16}$$

and:

$$\tau_0 = \rho |u_f| u_f \tag{17}$$

The boundary condition at the top of a boundary layer reads:

$$u(\delta + \frac{k_s}{30}, t) = U(t) - V \tag{18}$$

and, accordingly to adaptation of the logarithmic velocity profile, it converts to the formula:

$$\delta = \frac{k_s}{30}(e^{z_1} - 1) \tag{19}$$

in which:

$$z_1 = \frac{\kappa U}{u_f + u_{f0}} \tag{20}$$

After transformations one obtains Eq. (15) in the form:

$$\frac{dz_1}{d(\omega t)} = \frac{30z_1^2\left[\left|\frac{\kappa U}{z_1} - u_{f0}\right|\left(\frac{\kappa U}{z} - u_{f0}\right) + u_{f0}^2\right]}{\omega k U[e^{z_1}(z_1-1)+1]} - \frac{z_1(e^{z_1} - z_1 - 1)}{e^{z_1}(z_1-1)+1}\frac{1}{U}\frac{dU}{d(\omega t)} \tag{21}$$

In the above equation the ***nonlinear wave input*** $U(t)$ is involved, given by any Stokes approximation (for instance of 2nd or 3rd order, cf. discussion on the mathematical description of wave in Part 1 – Section 2.1).

The solution of Eq. 21 is obtained by the Runge–Kutta second-order method with the assumptions and slight simplifications of the case of nonlinear waves without current, cf. the solution of Eq.(13) in Part 1. As a result of computations the function $z_1(\omega t)$ is obtained and the time distributions of friction velocity $u_f(\omega t)$ and boundary layer thickness $\delta(\omega t)$ is determined on the basis of Eqs. (19) and (20), respectively. Then one can easily calculate the root mean square friction velocity u_{fc} (Equations 20 and 21 of Part 1).

The nonlinear wave versus a steady current is the most interesting case from a practical point of view, e.g. as to the resultant shear stress and the direction of the resulting flow. Therefore the quantity u_{fc} is of a great importance: if it is positive the effects of wave asymmetry will prevail and the mean flow in the wave–current boundary layer will be directed shorewards, if u_{fc} is negative the steady current will prevail and the resultant flow in the boundary layer will be directed seawards. For both situations the mean velocity profile can be calculated from Eqs. (13) for the range $< k_s/30; \delta_m/4 + k_s/30 >$ and (14) for the range $(\delta_m/4 + k_s/30; \delta_m/2 + k_s/30 >$ as in the case of nonlinear wave and current interaction the shear stress is assumed as constant in the range $< k_s/30; \delta_m/2 + k_s/30 >$. The choice of the upper limit where the shear stress is constant is rather arbitrary but it follows an assumption made with respect to wave boundary layer, cf. the discussion in Kaczmarek & Ostrowski (1992) – Part 1. In the range $(\delta_m/2 + k_s/30; 2\delta_m + k_s/30 >$ the mean velocity profile is assumed to change linearly upwards and to attain the value of slip velocity at the top of boundary layer. To analyse and distinguish the two major types of waves propagating against a current, sample computations have been made for the wave parameters corresponding to the laboratory experiment by Jonsson & Carlsen (1976): $h = 10$ m, $H = 5.3$ m, $T = 8.39$ s. The wave has been approximated by Stokes theory of 2nd order. Additionally three currents of different slip velocities have been assumed: $V = 0.20$ m/s, $V = 0.35$ m/s and $V = 0.70$ m/s. The resultant mean velocity distributions (solid line) in comparison with the profiles obtained for sinusoidal wave and current interaction (dashed line) are depicted in Fig. 4.

The equation of oscillatory motion and the boundary conditions have the same form as for the case of waves without current, i.e.:

$$\frac{\partial u_d}{\partial t} = \frac{\partial}{\partial z}\left(\nu_t \frac{\partial u_d}{\partial z}\right) \tag{22}$$

The following approximate initial condition is assumed:

$$u_d(z, t_0) = 0 \tag{23}$$

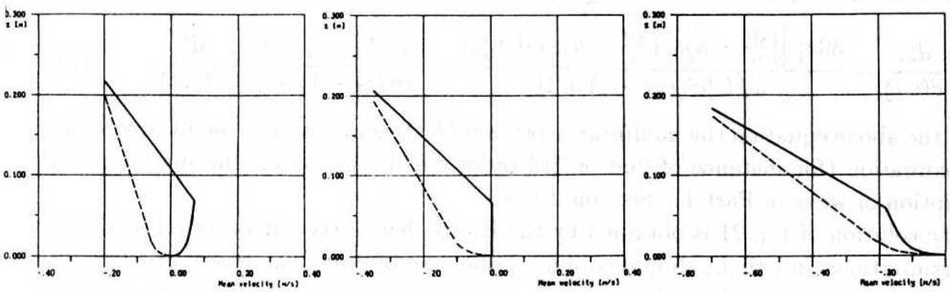


Fig. 4. Mean current velocity distributions in boundary layer as a result of interaction between nonlinear (solid line) or sinusoidal (dashed line) waves and a current

and the boundary conditions are:

$$u_d(\frac{k_s}{30}, \omega t) = -U(\omega t) \tag{24}$$

$$u_d(2\delta_m + \frac{k_s}{30}, \omega t) = 0 \tag{25}$$

The distribution of turbulent viscosity $\nu_t(z)$ given by the formulas (10) is inherent in the solution. Let us notice that this distribution is based on the friction velocity $\hat{u}_f$, which couples the effect of current and wave asymmetry (determined within the two–stage approach). The equivalent friction velocity $\hat{u}_f$ has been assumed as:

$$\hat{u}_f = \max\left(|u_f(\omega t)|\right) \tag{26}$$

while the mean boundary layer thickness is proposed as:

$$\delta_m = \max\left(\delta_1, \delta_2\right) \tag{27}$$

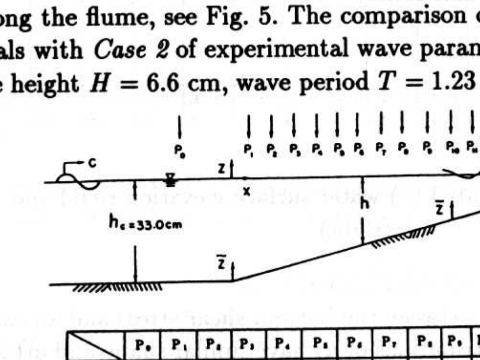
where δ_1 and δ_2 are the boundary layer thicknesses at the moments corresponding to maximum and minimum total (oscillatory and current) input, respectively.

Having solved the equation of motion in the same manner as for waves without current one may superimpose the instantaneous velocity profiles determined by numerical solution of Eq. (22) on the mean current distribution given by Eqs. (13) and (14) in the range $< k_s/30; \delta_m/2 + k_s/30 >$. In the range $(\delta_m/2 + k_s/30; 2\delta_m + k_s/30 >$ the mean velocity profile changes linearly upwards and attains the value of slip velocity at the top of boundary layer. This mean current velocity is also superimposed on the instantaneous velocity distributions.

3.2. Comparison between theory and measurements

In general one possesses a formula for the mean flow distribution outside the boundary layer, see discussion in Kaczmarek & Szmytkiewicz (1991), containing the unknown slip velocity V. This quantity can be determined by a rather complicated but precise iterative scheme given in Kaczmarek & Ostrowski (1991), with the improvements proposed in Section 2.

The comparisons have been made between results of computations and the laboratory measurements of Hwung & Lin (1990). The experiments were carried out in a $9.5\times0.7\times0.3$ m wave tank in which the bottom was adjusted on slope 1:15. The velocities of water were measured in 13 testing sections (including the boundary layer) situated along the flume, see Fig. 5. The comparison of computed results and measurements deals with *Case 2* of experimental wave parameters: initial depth $h = 0.33$ m, initial wave height $H = 6.6$ cm, wave period $T = 1.23$ s.



	P_0	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}
d(cm)	33.0	22.8	19.6	17.4	15.7	14.5	13.0	11.4	11.0	9.8	8.5	7.4	6.1

Fig. 5. The sketch diagram of testing sections, Hwung & Lin (1990)

Although it is possible to provide the complex solution in the outer region using one of the models dealing with return flow and in the boundary layer using the present approach, it is worthwhile to focus attention on the precision of solution in the boundary layer, being a major topic of the paper. Therefore the value of the slip velocity V has been taken from the survey results to obtain the best fit of the boundary condition at the upper limit of boundary layer.

The computed and measured instantaneuos velocity profiles have been compared for the testing section $P4$. The water surface elevation $\zeta(\omega t)$ and the wave input $U(\omega t)$ have been determined by the theory of Borgman and Chappelear (Stokes approximation of 3rd order), Fig. 6. The assumed time distributions of $\zeta(\omega t)$ and $U(\omega t)$ have been a little bit shifted to obtain the best fit with respect to the registered ones.

The instantaneous velocity profiles and the temporal distribution of the friction velocity $u_f(\omega t)$ have been computed using the procedure presented in the previous section. The equivalent roughness k_s has been estimated as 2 mm. The velocities are given in Fig. 7, while the boundary layer thickness $\delta(\omega t)$ and the friction velocity $u_f(\omega t)$ are depicted in Fig. 8. Additionally, the temporal distribution of u_f calculated on the basis of instantaneous velocities (see Eqs. 19, 49 and 50 in Part 1) are plotted as a bold line. This distribution seems to be better because it represents a characteristic

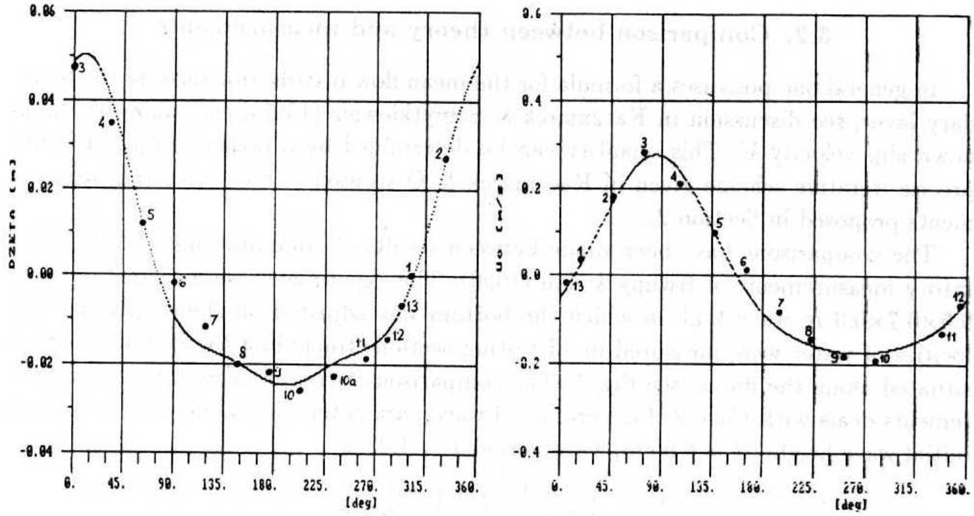


Fig. 6. Measured (•) and calculated (–) water surface elevation (left) and wave input (right)

(physically justified) phase shift between the bottom shear stress and an external wave input. Apart from this, both distributions of u_f have similar shape and attain the same maximum value. The agreement of computed and measured instantaneous velocity profiles is satisfactory, especially at the moments corresponding to the best fit between registered and assumed wave inputs $U(\omega t)$.

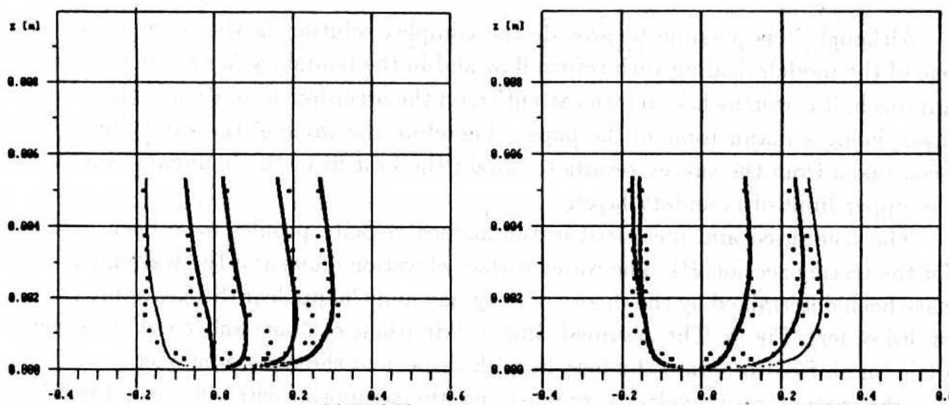


Fig. 7. Measured (•) and computed (–) instantaneous velocity distributions

The calculated mean velocity profiles for the testing sections $P1$, $P3$, $P4$ and $P6$ are given in Fig. 9. In general, they all correspond to the measured ones very well. As

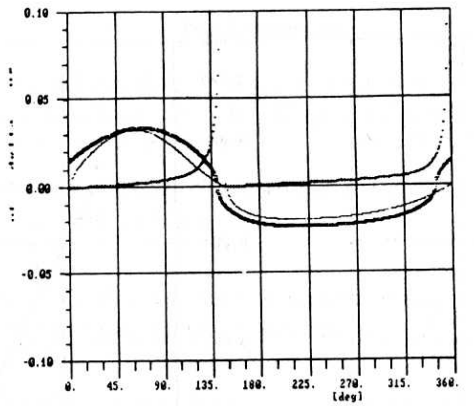


Fig. 8. Boundary layer thickness $\delta(\omega t)$ and friction velocity $u_f(\omega t)$

the testing section $P1$ lies in the range of application of Stokes 2nd order theory, the velocity has also been determined for that approximation (dashed line).

4. Conclusions

A theoretical model describing both instantaneous and time–averaged quantities of velocity and friction inside the turbulent boundary layer generated by interacting nonlinear wave and current has been presented. The analysis in the paper is restricted to the two–dimensional flow in which the angle between the direction of wave propagation and steady current is either 0^o or 180^o. The model takes into account nonlinear effects, i.e. wave asymmetry and the effects associated with $\overline{Uw_\infty}$ term.

The theoretical formula of eddy viscosity in the outer (undertow) region has been proposed and next employed in the mathematical description of undertow.

The effect of $\overline{Uw_\infty}$ (associated with energy dissipation in a wave boundary layer) on the undertow distribution has been evaluated for one of the cases of Buhr–Hansen & Svendsen's (1984) experiment. The contribution of this term has been found to be very small. This implies that the proposed formula for slip velocity obtained with the assumption of zero undertow shear stress at the bottom is sufficient for practical engineering purposes.

The results of computations of velocities inside the boundary layer under nonlinear wave and current have been compared with the laboratory data of Hwung & Lin's (1990) experiment. The agreement of computed and measured both instantaneous and mean velocity profiles is satisfactory.

Acknowledgements

The study has been sponsored by KBN and PAN, Poland, under programme 2 IBW PAN, which is hereby gratefully acknowledged. The Authors wish to thank Prof. R. Zeidler for the collaboration and help throughout the study.

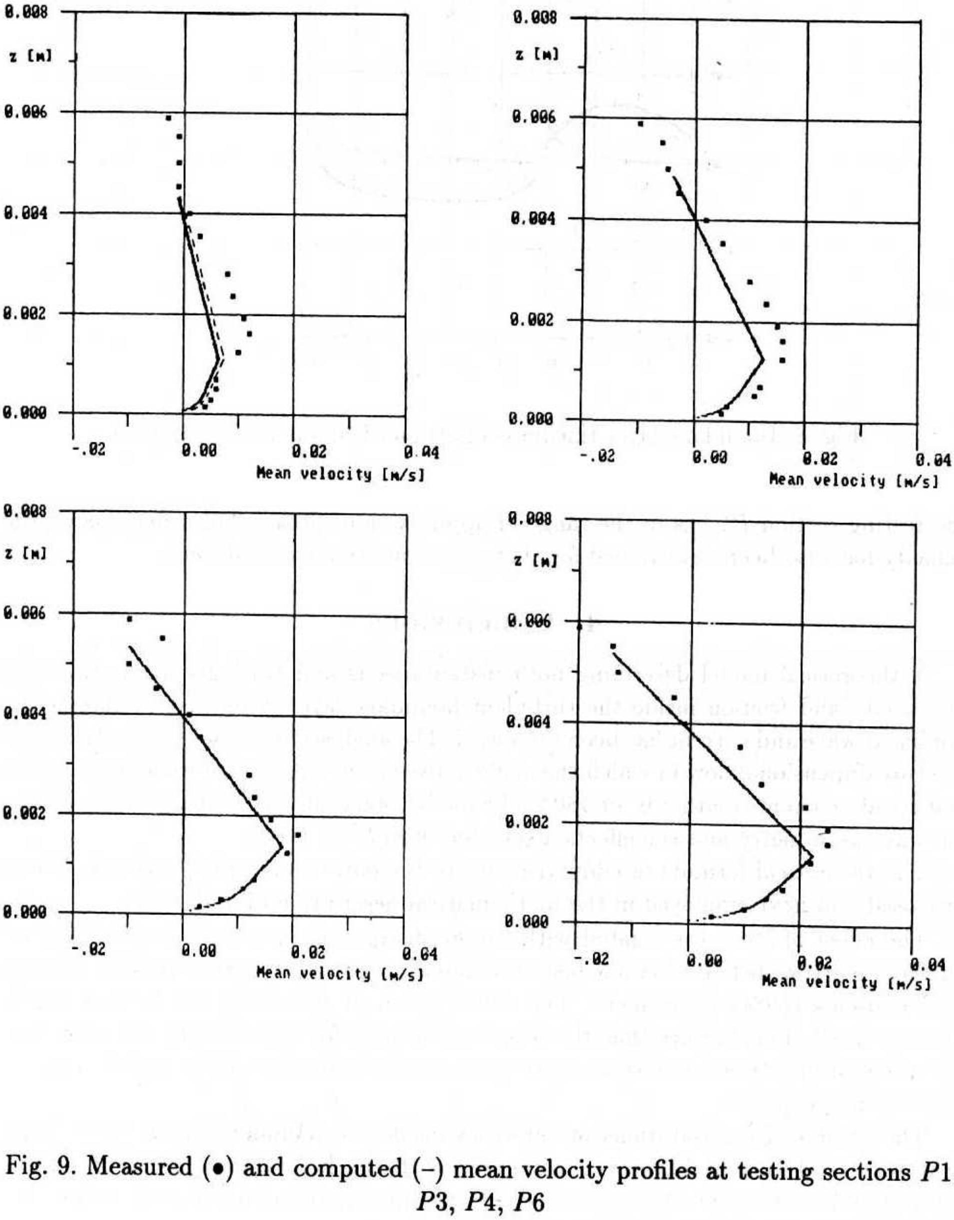


Fig. 9. Measured (•) and computed (–) mean velocity profiles at testing sections $P1$, $P3$, $P4$, $P6$

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Summary

A theoretical model describing both instantaneous and time–averaged quantities of velocity and friction inside the turbulent boundary layer generated by interacting nonlinear wave and current has been presented.

The results of computations of velocities inside the boundary layer under nonlinear wave and current have been compared with the laboratory data of Hwung & Lin's (1990) experiment. The agreement of computed and measured both instantaneous and mean velocity profiles is satisfactory.

Streszczenie

Dynamika falowo – prądowej warstwy przyściennej
Część 2
Modelowanie turbulentnej warstwy przyściennej w warunkach nieliniowego współoddziaływania fal i prądów

W pracy przedstawiono chwilowe i uśrednione w czasie rozkłady prędkości i tarcia wewnątrz turbulentnej warstwy przyściennej generowanych przez nieliniowe współoddziaływanie fal i prądów. Obliczone rozkłady prędkości porównano z danymi laboratoryjnymi Hwung i Lina 1990. Uzyskano dobrą zgodność rozkładów prędkości zarówno chwilowych jak i uśrednionych w czasie.