DRIFT CURRENTS OF CLEAN AND SLICK SEA SURFACES

Jin Wu[1]

1 INTRODUCTION

Drift currents near sea surface govern movement and dispersion of man-made discharges near the sea surface, and influence design, deployment, and stability of offshore structures. The wind-induced drift currents and the wave-induced mass transports at the sea surface are separately estimated. The total surface drift current, the sum of wind- and wave-induced components, agree well with oceanic data (Hughes, 1956).

The mass transport of waves over slick surface is greater than that over clean surface due to dynamic interactions between the surface film and waves. On the other hand, the wind-stress coefficient of slick surface is smaller than that of clean surface, resulting in a smaller wind-induced drift current over the slick surface. Available laboratory results (Alofs and Reisbig, 1972) on slick movements are reanalyzed to provide basis for estimating movements of slicks of various sizes over waves of different lengths under different wind velocities.

2 DRIFT CURRENTS OF CLEAN SURFACE

2.1 Experiments in Laboratories

A slow forward motion of water particles under surface waves was theoretically predicted by Stokes (1847). The so-called Stokes transport at the water surface, V_v, can be expressed as

$$V_v = \sigma a^2 k \tag{1}$$

where σ, a, and k are the radian frequency, amplitude, and wave number of waves, respectively. Experimental observations of (1) were provided, among others, by Lange and Hühnerfuss (1978).

Studies on drift currents in a wind-wave tank have been conducted by Wu (1975). The difference between measured total drift current and estimated Stokes transport was considered as the wind-induced current. The wind-friction velocity was suggested (Wu, 1975) as the proper parameter for correlating this wind-induced component,

$$V_n/u_* = 0.53 \tag{2}$$

where V_n is the wind-induced surface drift current, and u_* is the friction velocity of the wind.

[1]Professor of Civil Engineering and Marine Studies, University of Delaware, Newark, Delaware 19711.

2.2 Estimations for Field

The Stokes surface transports at various fetches under different wind velocities can be obtained from (1) with wave data reported in Wu (1969),

$$V_v/U_z = 0.0186\ (gL/U_z^2)^{0.03} \qquad (3)$$

where g is the gravitational acceleration, L is the fetch, and U_z is the wind velocity at the elevation z above the mean sea surface.

In the meantime, the wind-induced shear current can be obtained from (2) with empirical wind-stress (Wu, 1980) and wave-drag coefficients. Combining wind- and wave-induced components, the ratio between the total surface-drift current and the reference wind velocity (V/U_z) decreases with increasing fetch at short fetches, and is independent of fetch at long fetches. The total surface drift current is about 3.1% wind velocity at very long fetches.

2.3 Comparison with Other Results

From the equilibrium wave spectrum (Phillips, 1977), Bye (1967) obtained an expression for the Stokes surface transport. Accepting the value of the spectral coefficient suggested by Longuet-Higgins (1969) for the open sea, we obtained from Bye's expression: $V_v/U_{10} = 0.0274$. This is in fair agreement with the present estimate of the mass transport. More recently, the spectral coefficient was found to vary with both fetch and wind velocity (JONSWAP). Coupling these results with Bye's expression, the mass transport at the sea surface decreases with fetch and increases with wind velocity, having the same trend as the present estimate.

An expression similar to (3) was proposed by Kondo (1976). The surface mass transports calculated from Kondo's and the present expressions for U_{10} = 10 m/s at various fetches are shown in Table 1. In comparison with the present as well as other results, such as those discussed above, Kondo's estimate appears to provide rather low values.

Fetch (km)	10	50	100	500	1000	5000
Kondo (1976)	1.63	1.68	1.70	1.75	1.77	1.82
Equation (3)	2.29	2.40	2.45	2.57	2.63	2.95

Table 1. Ratios (%) Between Estimated Surface Mass Transport and Wind Velocity for U_{10} = 10 m/s.

The drift currents at the sea surface were measured by Hughes (1956) with plastic envelopes floating close to the water surface. He found that the water within 1 cm or so of the surface drifted parallel to the wind. The drifting speeds of plastic envelopes were about 3.1% of the wind velocity. This value coincides with the present estimate.

3 DRIFT CURRENTS OF SLICK SURFACE

3.1 Increase of Surface Mass Transport

Experiments have been conducted by Alofs and Reisbig (1972) to investigate wave-induced drifts of simulated oil slicks in a wave tank. Floats made of

thin, flexible plastic sheets of various sizes were laid on the water surface before the experiment, and were found to conform with the wavy surface. The drift of floats due to waves, verified to be very similar to that of oil lens, was measured with waves of two different lengths and various steepnesses. For each experimental condition, we obtained an equilibrium drift velocity V_{max}, at which the drift current no longer increased with the float length, ℓ. Inasmuch as the mass transport over the clean surface in Alofs and Reisbig's experiments was found to be greater than V_v, we determined the additional movement due to the presence of float from $V_{max}-V_o$, where V_o is the velocity of the "float of zero length" found by extending their results obtained with floats of various lengths to $\ell = o$.

As discussed earlier, the leeway between the transports of slick and clean surfaces increases with the film length, and the maximum leeway is produced by the film with its length approaching the wavelength. Consequently, when the ratio between the measured and the maximum leeways is plotted versus the ratio between the float and the wave lengths, the movements of floats over waves of not only various steepnesses but also various lengths can be incorporated with a nondimensional relation expressed as

$$(V_f-V_o)/(V_{max}-V_o)=1-(3/4)\ \log\ (\ell/\lambda) \quad \text{for } \ell/\lambda < 1$$
$$(V_f-V_o)/(V_{max}-V_o)=1 \quad \text{for } \ell/\lambda < 1 \qquad (4)$$

where V_f is the measured float velocity, and λ is the wavelength.

The floats of monolayers were used by Lange and Hühnerfuss (1978) in their experiments. The length of floats was longer than the length of waves tested (20 cm < λ < 70 cm). They found no streaming effects with the drift velocity of floats following very closely the Stokes surface transport.

3.2 Decrease of Wind-Induced Surface Currents

Effects of the monolayer upon the wind structure have been studied in the field by Barger et al. (1970). Vertical wind profiles were measured over clean and slick surfaces, and were verified to follow the logarithmic distribution,

$$U_z/u_* = (1/\kappa)\ \ell n\ (z/z_o) \qquad (5)$$

where κ is the Karman universal constant, and z is the roughness length. Values of z_o and u_* for both the clean and slick surfaces were obtained by Barger et al. The presence of monolayer causes damping of small waves; consequently, the roughness length was drastically reduced. The transition of the wind boundary layer, therefore, occurred at a higher wind velocity, approximately 6 m/s. Below this wind velocity, the roughness length of the slick surface is about the same as that of the clean surface. The similarity in roughness lengths for clean and slick surfaces at high wind velocities is believed to be due to disruption of the surface film by wind.

As expected, the variation of the wind-friction velocity has similar features; for the same wind velocity the friction velocity for the surface covered with monolayers is much greater than that for the surface without.

Before the disruption of the monolayer, the wind velocity for the surface covered with the monolayer is about twice that for the clean surface having the same friction velocity. Because the wind-induced drift current is proportional to the wind-induced surface drift current, the wind velocity for the slick surface is, therefore, about one-half that for the clean surface.

No similar study has been reported with wind blowing over water surface covered by oil slicks.

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