CHAPTER 22

Determination of Wind Stress (Drag) Coefficient for Coastal Waters Under Variable Meteorological and Oceanographic Conditions

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Abstract

On the basis of a parametric model of wind stress (drag) coefficient over water surfaces and related experiments, objective procedures to obtain this coefficient under variable wind and wave conditions are outlined and recommended for oceanographic applications and air-sea interaction studies. Methods for both fully and non-fully developed sea conditions are given.

1 Introduction

Wind stress, τ, is one of the most important parameters for air-sea interaction studies see, e.g., Roll, 1965, for momentum flux; Bishop, 1984, for upwelling (current) computation . In order to obtain the magnitude of the wind stress, the drag coefficient is commonly used, i.e.,

$$\tau = \rho U_*^2 = \rho C_D U_z^2 \tag{1}$$

where ρ is the air density, U_* is the shear (or friction) velocity, and C_D is the drag coefficient, which corresponds to the wind speed, U_z, at height z above the water surface.

Variation of C_D with wind speed has been the subject of many investigations (see, e.g., a list given Blanc, 1985). An illustration is provided in Figure 1. In order to explain the increase of C_D with wind speed, Hsu (1986a) has proposed a mechanism that incorporates contributions by both wind and waves. These parameters are modeled into an aerodynamic roughness equation that has proven to be applicable in both coastal waters and open-ocean conditions.

It is the purpose of this paper to outline the procedures necessary for objective computation of the drag coefficient over coastal waters, where meteorological and oceanographic conditions are constantly changing because of variable fetch, duration, and speed of the wind, which in turn produces different characteristics of the wind waves.

2 Procedures

In order to compute C_D, the following objective procedures are recommended:

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(1) Obtain existing wind records, U_{Land}, from a nearby Weather Service station at a local airport in the coastal plain. Transpose U_{land} to the offshore region by an equation (shown in Fig. 2) provided by Hsu (1986b), i.e.,

$$U_{sea} = 1.62 + 1.17\ U_{land} \tag{2}$$

where the units of U_{sea} and U_{land} are in meters per second.

(2) If the anemometer at the official airport is not located at the conventional height of 10 m above the surface, correct by first using Eq. (2) and then applying the following equation:

$$\frac{U_{10}}{U_{sea}} = \left(\frac{10}{z}\right)^{0.1} \tag{3}$$

Note that if one applies Eq. (2) to the inland region the exponent should be changed. However, owing to complicated geomorphological features onshore, the value of the exponent is less certain than that of the offshore region, as shown in Eq. (2), which was verified by an experiment with tethered balloon soundings in the atmospheric boundary over the Mediterranean Sea, as shown in Figure 3 (Hsu, 1986c).

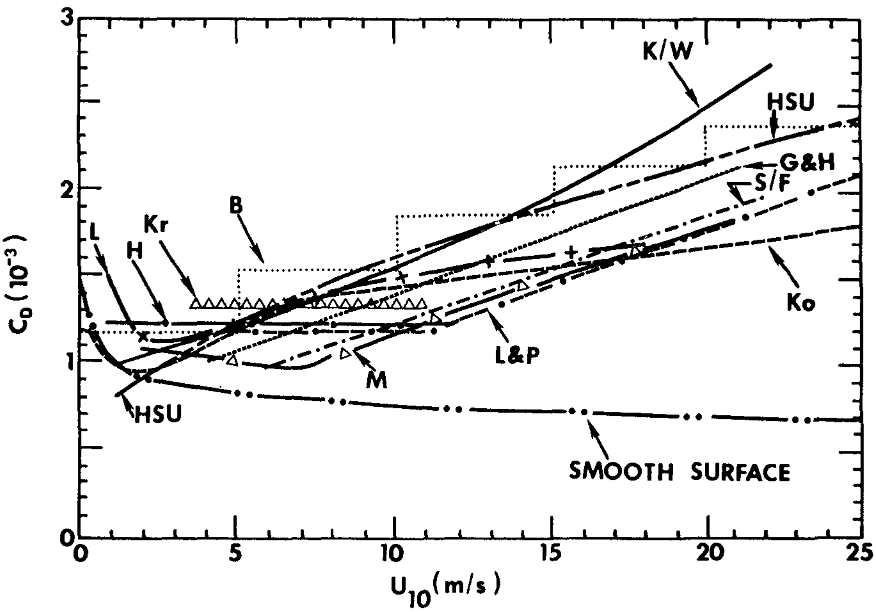

Fig. 1. Variation of the drag coefficient, C_D, with wind speed at 10 m above the sea surface from Blanc, 1985, except the curve labeled "Hsu, this study," which is based on Eq. (4) .

(3) For engineering applications, assume first that the sea is fully developed. According to Hsu (1986a, Eq. 35), we have

$$C_{10} = \left[\frac{\kappa}{14.56 - 2 \ln U_{10}}\right]^2 \tag{4}$$

where κ is the von Karman constant (= 0.4 $\pm$ 0.01; see Hogstrom, 1985).

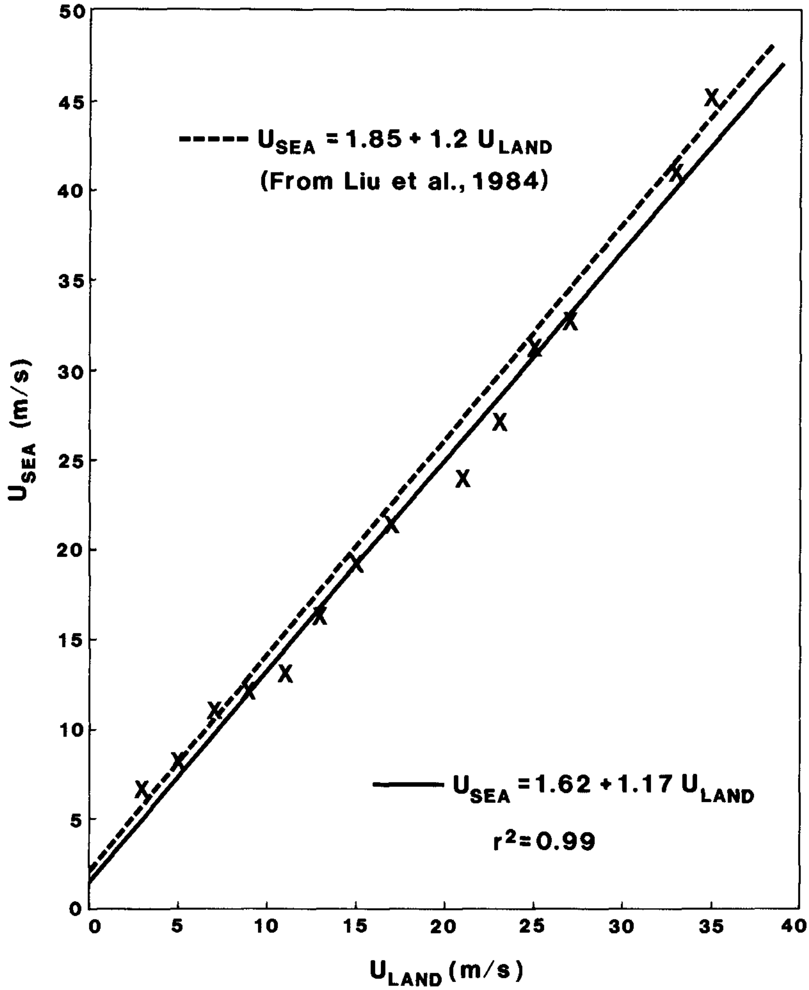

Fig. 2. Variation of U_{sea} as a function of U_{land} (from Hsu, 1986b).

This equation is shown as the curve labeled "HSU" in Figure 1, which is obtained from wind and wave parameterization and is consistent with measurements. Additional verification of Eq. (4) is given in Figure 4 as well as in Hsu (1986a).

(4) If the sea is not fully developed and detailed wind-stress estimates are needed to compute the currents, e.g., during oil spill conditions, the following procedures may be applied. From forecasted weather maps, the fetch, duration, direction, and speed of the wind near the sea surface can be obtained (see, e.g., procedures outlined in U.S. Army Corps of Engineers, 1984). On the basis of these data, wave celerity, C, and significant

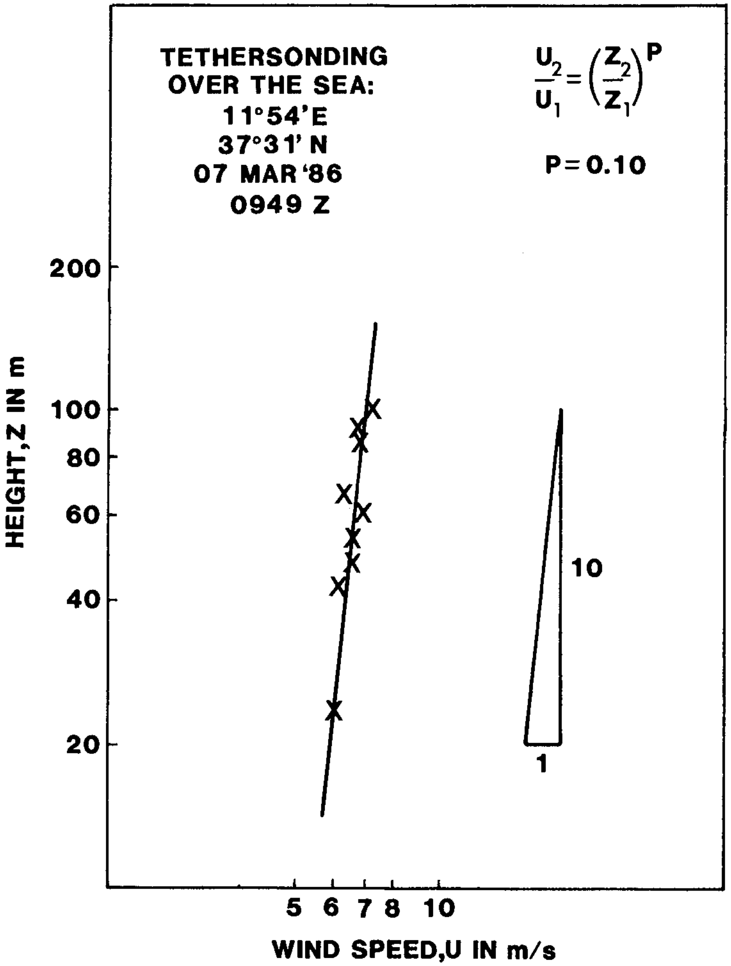

Fig. 3. A log-log plot of U versus Z over the ocean (from Hsu, 1986c).

wave height, $H_{1/3}$, can be computed. A quick way is to use the nomogram provided in U.S. Army Corps of Engineers (1984).

With wind and wave parameters, U_* can be estimated from the nomogram provided in Figure 5 (Hsu, 1976). Then, applying the following formula from Eq. (1):

$$C_D = (U_*/U_z)^2 \qquad (5)$$

Note that the effect of atmospheric stability has already been incorporated in the wave characteristics (see Hsu, 1976; Janssen and Komen, 1985).

3 CONCLUSIONS

On the basis of a parametric model of wind stress (drag) coefficient and related experiments, objective procedures to obtain C_D are outlined and recommended for oceanographic applications. These procedures should be useful for coastal engineers.

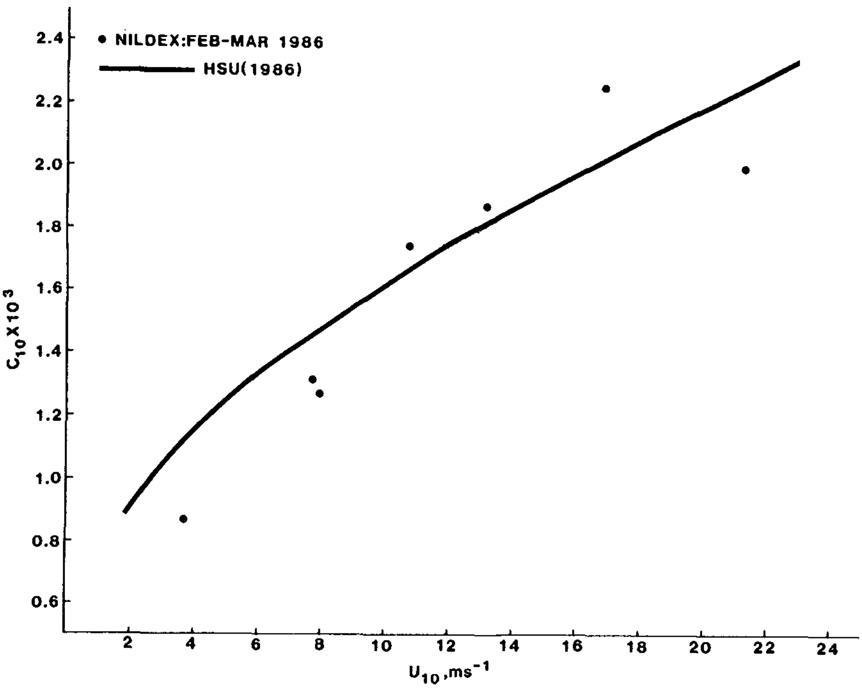

Fig. 4. Variations of C_{10} versus U_{10} as obtained from the Mediterranean Sea (see Hsu, 1986c). The solid line is based on Eq. (4).

4 ACKNOWLEDGEMENT

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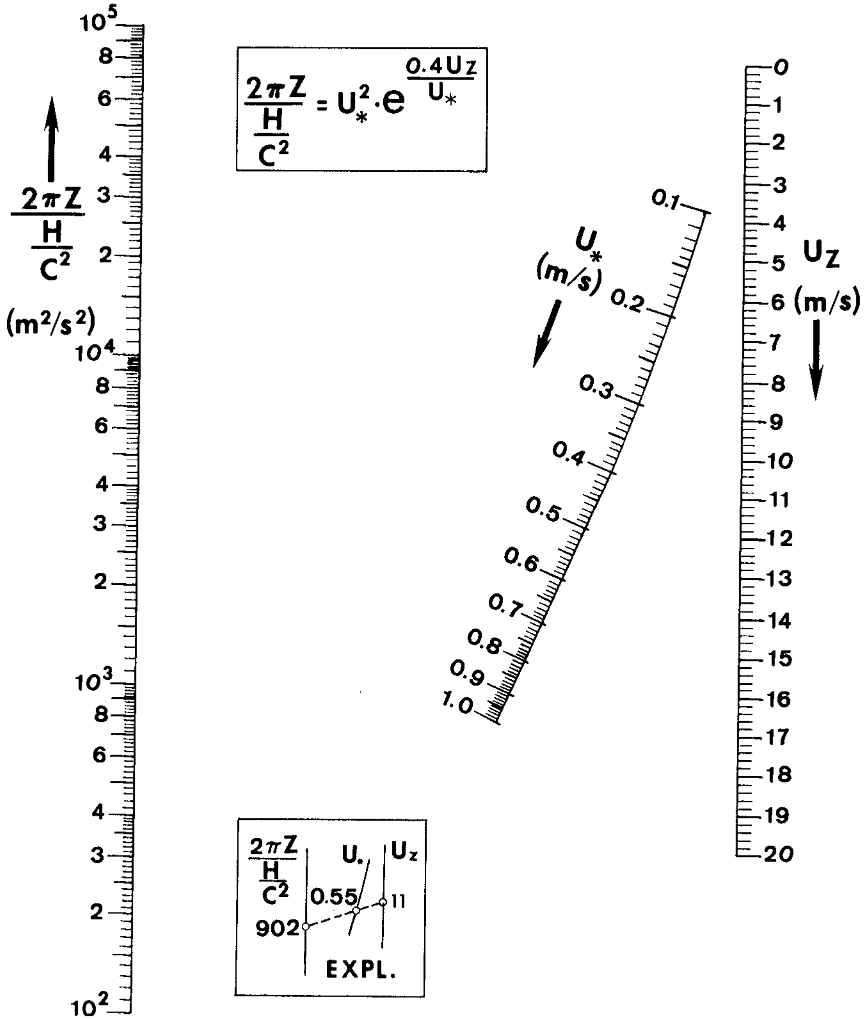

Fig. 5. A nomograph for computing U_* from wind and wave parameters for both fully and non-fully developed sea conditions. The figure gives an example of the use of commonly available wind (U_z) and wave (H and C) parameters to obtain U_* (Hsu, 1976).

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