Experimental investigation of turbulent boundary layer beneath a wind-driven water surface

SUGIHARA Y.¹, H. TSUMORI¹, A. TAKASAKI²

¹Earth System Science and Technology, Kyushu University, Japan
²Daiichi-fukken, Japan

Quantitative properties of turbulent boundary layer beneath a wind-driven water surface are investigated by means of laboratory experiments, which are carried out using a wind-wave tank, 17m long, 0.6m wide and 0.8m deep. Instantaneous streamwise, transverse and vertical velocities in the water are measured at a fetch of 10.75m by using a three-component acoustic Doppler velocimeter, and they are obtained at reference wind speeds of 5.0, 7.5 and 10m/s. Wind speeds and surface displacements are also measured using a Pitot-static tube and capacitance-type wave gauges, respectively.

Power spectra of the velocity fluctuations show that a spectral region in proportion to \(-\frac{5}{3}\) power of the frequency \(f\) forms over a frequency range lower than the peak frequency due to dominant waves \(f_p\). Also, the turbulence in ranges \(f < 0.1\text{Hz}\) and \(f > f_p\) is found to be anisotropic. It is seen from cospectra of the streamwise and vertical velocity fluctuations that in the region of low wind speeds, most of the Reynolds stress is contained in a lower frequency range than \(f_p\), and that the Reynolds stress around \(f_p\) becomes large with increasing the wind speed and is decreased exponentially with increasing the water depth.

Turbulent velocity fluctuations at lower frequencies than \(f_p\) are separated from wave-induced velocity fluctuations on the basis of simple cutoff filters. Vertical profiles of the turbulent intensities, the Reynolds stress, the turbulent energy and the turbulent energy flux are obtained from the turbulent fluctuations. These profiles nondimensionalized with the friction velocity and the roughness length on the waterside become independent of the wind speed, i.e., they can be expressed universally. On the other hand, the vertical profiles obtained from the wave-induced fluctuations can be described on the basis of the small-amplitude wave theory.

Taylor’s hypothesis enables us to transform frequency spectra of turbulence into wavenumber spectra. The dissipation rate of the turbulent energy is determined by applying a semi-empirical universal spectrum function to the wavenumber spectra. Vertical profiles of the dissipation rate can be expressed universally by using the friction velocity and the roughness length as well as the other turbulent characteristic quantities. The values of the dissipation rate close to the water surface are increased by about ten times those based on the wall-layer scaling. The present data support that the vertical profiles of the dissipation rate agree approximately with a previous empirical relation, which was obtained from field observation data [Terray et al., 1996].

REFERENCES