PO.ID 185

Extrapolate surface velocity to hub height depending on sea state

Ali Al Sam, Robert Szasz, Johan Revstedt
Department of Energy Engineering, Lund University, Lund, Sweden

LUND UNIVERSITY

Abstract

The accurate prediction of flow characteristics in the offshore environment requires knowledge of the wind-wave interaction phenomena. Atmosphere and ocean are coupled dynamically by the momentum exchange at the air-sea interface. However, because of the difficulties of conducting accurate measurements close to the sea surface and scarcity of simultaneous measurements of ocean waves and winds, the sea state effects on momentum fluxes, and by that on the atmospheric boundary layer, are unclear. In order to understand the influence of sea state on vertical momentum flux, Large Eddy Simulations are used to investigate turbulence flows over various wave to wind speed ratio.

- Windsea is frequent in:
  - Enclosed sea
  - High wind
- Swell is frequent in:
  - Open oceans
- Swell can :
  - affect the near surface momentum transfer [1]
  - alter the wind velocity profile [2]
  - cause an upward momentum flux from the ocean toward the atmosphere [3]
  - cause a significant misalignment between winds and wind stress which invalidates the use of the MOST [2]

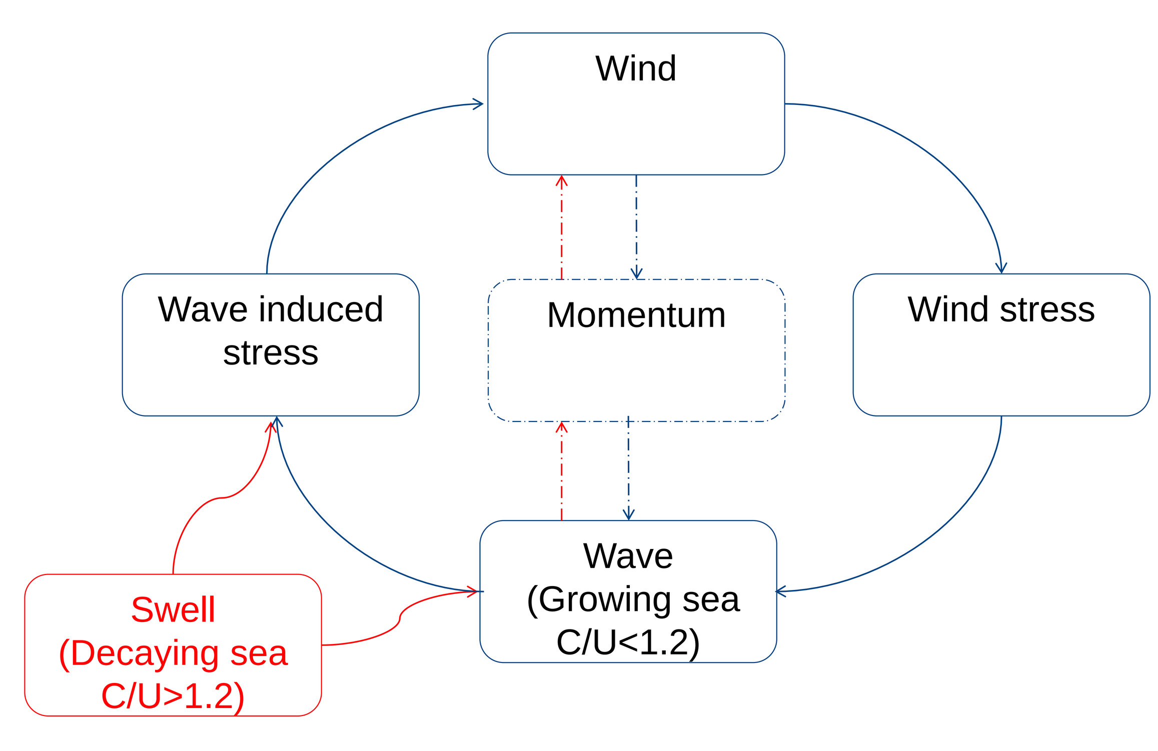

Figure 1: wind-wave coupling

Objectives

The wave effects are commonly thought to be limited to a few meters above the water surface and usually considered as an aerodynamic roughness. In order to derive the logarithmic wind profile from Monin-Obukhov Similarity Theory (MOST), the aerodynamic roughness is consistently treated in offshore wind energy applications either as a constant or as a function of friction velocity without regard to its dependency on the sea state(e.g. wave- age, steepness and shape). However, field observations and numerical simulations have shown that the impact of the waves, in particularly the non-locally generated waves(swell), on the atmospheric surface layer might be stronger than previously assumed [1-3].

Since all of the Theories that explain the water wave generation and the wave growth rate are limited to the locally generated waves, we do not know much about the swell effects. In order to take into account the wave induced stress at a high wave to wind speed ratio, The following questions should be answered:

- **How large is the wave-induced stress?**
- **How large is the wave boundary layer (the part of the atmosphere affected by the waves)?**

Methods

- Neutral Couette flow
  - Geometry (6λ, 3λ, 1λ), λ is the wave length.
  - Re=($\lambda U_\lambda/\nu$)=8000.
  - Wave to wind speed ratio (C/U_λ=1.2, 1,4, …, 3,6)
- LES Solver
  - OpenFOAM 2.1.3, 2nd order spatial and temporal schemes
  - LES with Lagrangian-averaged dynamic Smagorinsky
  - Fixed reference of frame
  - Laplacian moving mesh solver
- BCs
  - Periodic in horizontal directions
  - Fixed velocity at upper boundary
  - No-slip at lower boundary
- Prescribed wave motion
  - $\eta(x,t)=a\cos[(2\pi(x/\lambda - t/T)]$
  - Wave slope ak= 2 π a/ λ =0.1
  - wave attenuation is neglected
  - wave aligned with wind

Results

- The wave –induced stress (form drag):

$$D_o = \int_0^\lambda \langle p\rangle \frac{\partial\eta}{\partial x}\, dx \simeq \langle pw\rangle / C$$

Here, p is the air pressure at the wave surface, η is the wave surface height, w is the air vertical velocity and C is the wave phase speed.

- The dependency of the wave-induced stress at the wave surface on the wave to wind speed ratio is shown in Fig 2

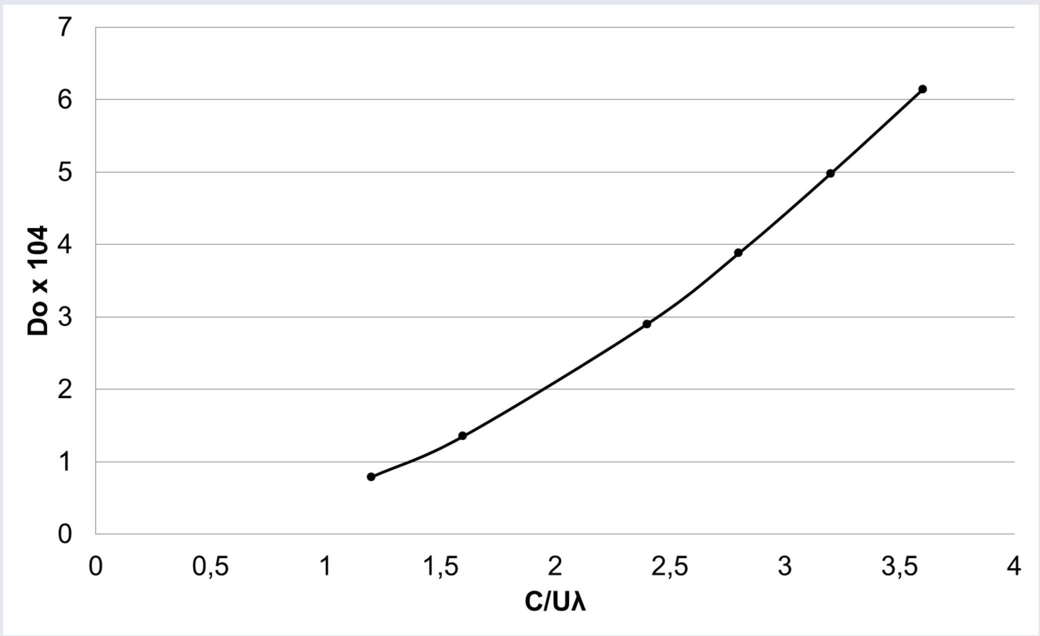

Figure 2: the wave induced stress at different wave to wind speed ratio.

- Furthermore, the results show that the decaying rate of the wave-induced stress is also a function of the wave to wind speed ratio, Fig 3:

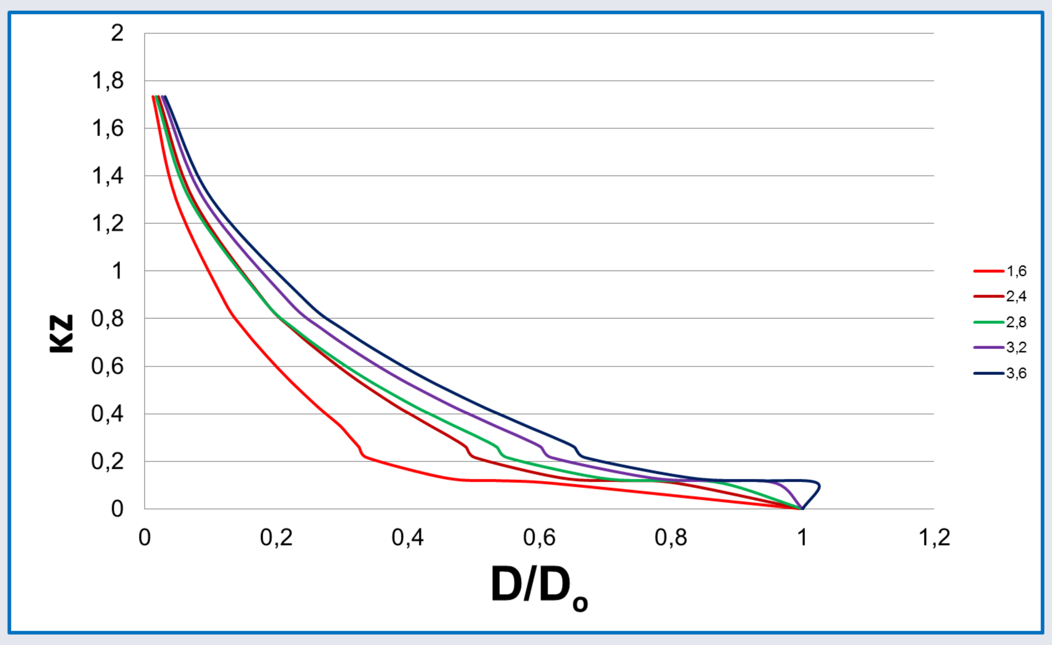

Figure 3: The decay of wave induced stress with the height above the wave surface.

Conclusions

- At a high wave to wind speed ratio, the wave-induced stresses are positive (upward).
- There is a direct dependency of the magnitude of the wave-induced stress on the wave to wind speed ratio.
- The wave boundary layer is found to be also a function of wave to wind speed ratio.

$$D_o\ X\ 10^4 = 0,56\left(C/U_\lambda\right)^{1,9}$$

$$D/D_o = e^{-akz}$$

$$a = \left(-0,35\left(C/U_\lambda\right) + 3,075\right)$$

Future works

- The above proposed parameterization of wave-induced stress based on the current study results will be tested for a wider range of wave slopes and wave to the wind speed ratio conditions.
- Studying the other parameters that can affect the value of the wave-induced stress such as the current velocity, wave shape and surface roughness.

References

1. F. Dobson, S. Smith and R. Anderson. Measuring the relationship between stress and sea state in the open ocean in the presence of swell. Atmos.-Ocean., 32: 236-237, 1994
2. A. Smedman, U. Högström, H. Bergström, A. Rutgersson, K. Kahma and H. Pettersson. A case-study of air-sea interaction during swell conditions. J. Geophys. Res., 104: 25833-25851, 1999
3. A. Grachev and C. Fairall. Upward momentum transfer in the marine boundary layer. J. Phys. Oceanogr., 31: 1698–1711, 2001