Inch Cape Offshore Wind Farm

New Energy for Scotland

Offshore Environmental Statement:
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Annex 10A.4: Bed Shear Stress Analysis Methodology

INCH CAPE OFFSHORE LIMITED

ANNEX 10.4 BED SHEAR STRESS ANALYSIS

TECHNICAL REPORT

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In order to assess the baseline sediment regime and the potential impacts of the proposed development on metocean and coastal processes, the bed shear stresses induced by hydrodynamic and wave processes were determined. These were then assessed against the critical entrainment stress, in order to determine the percentage of time for which this critical shear stress is exceeded.

Both currents and waves (due to the wave orbital velocity) generate a bed shear stress, and these can be calculated individually using well-established equations. The total bed shear stress, i.e. the combined force due to currents and waves, can also be calculated, although it should be noted that this is not simply the sum of the bed shear stresses due to currents and waves separately.

This Appendix provides details of how the bed shear stress and the critical entrainment stress have been calculated. All of the equations used have been taken from Soulsby (1997).

A.4.1 BED SHEAR STRESS DUE TO CURRENTS

The equation used to determine the bed shear stress due to tidal currents only is Equation 30 in Soulsby (1997):

$$\tau_c = \rho * C_D * U^2 \qquad \textbf{Equation 1}$$

where:

τ_c = bed shear stress due to tidal current

U = depth-averaged tidal current

ρ = density of seawater

C_D = drag coefficient applicable to depth-averaged current – from Equation 37 (Soulsby, 1997):

$$C_D = (0.4 / (1 + \mathrm{Ln}(Z_o/d)))^2$$

where:

z_0 = bed roughness length

d = depth

Depth-averaged tidal current speeds were extracted from the Forth and Tay Modelling System (FTMS) hydrodynamic model. In order to determine the range of percentiles of bed shear stress due to currents, as required for the assessment, the 50, 90, 95 and 99-percentiles of depth-averaged current speed (taken from the mean spring and mean neap tides) were calculated for each model element across the model domain.

A spatially varying map of median grain size (d_{50}) was also calculated across the domain (see Appendix 10A), and from this the required drag coefficient (C_D) was determined. Using the spatially varying percentile values for U (extracted from the FTMS), and the spatially varying values of C_D, the percentiles of bed shear stress due to currents (τ_c) were calculated (using Equation 1 above) at each model element.

A.4.2 BED SHEAR STRESS DUE TO WAVES

The equation used to determine the bed shear stress due to wave-induced currents only is Equation 57 (in Soulsby, 1997). This is shown below.

$\boldsymbol{\tau_w = 0.5*\rho*f_w*U_w^2}$ **Equation 2**

where:

τ_w = bed shear stress due to wave orbital current

ρ = density of seawater

U_w = wave orbital velocity amplitude at the bed

f_w = wave friction factor given by:

$f_w = 0.3$ for $r \leq 1.57$ or $f_w = 0.00251*\exp(5.21*r^{-0.19})$ – from Equation 60a and 60b (Soulsby, 1997), where:

$r = A/k_s$ – from Equation 58b (Soulsby, 1997)

$A = U_w T/2\pi$

k_s = Nikuradse equivalent sand grain roughness

T = wave period

The required wave parameters (wave orbital velocity at the bed and wave period) were obtained from the FTMS spectral wave model output. The bed shear stress was then calculated across the model domain for each of the different wave scenarios modelled, and the percentage frequencies of occurrence for different bed shear stress values were determined by summing the probability of occurrence associated with each modelled wave scenario. In this way, an exceedence curve for bed shear stress was generated, from which the 50, 90, 95 and 99-percentiles of wave-induced bed shear stress were determined.

A.4.3 BED SHEAR STRESS DUE TO COMBINED CURRENTS AND WAVES

The equations used to determine the bed shear stress during a wave cycle under combined currents and waves are Equation 69 (for mean stress), and Equation 70 (for maximum stress) (in Soulsby, 1997). These are shown below:

Mean bed shear-stress:

$\boldsymbol{\tau_m = \tau_c [1 + 1.2(\tau_w/(\tau_c + \tau_w))^{3.2}]}$ **Equation 3**

where:

τ_c = bed shear stress due to currents only (calculated from Equation 1)

τ_w = (mean) bed shear stress due to waves only (calculated from Equation 2)

Maximum bed shear-stress:

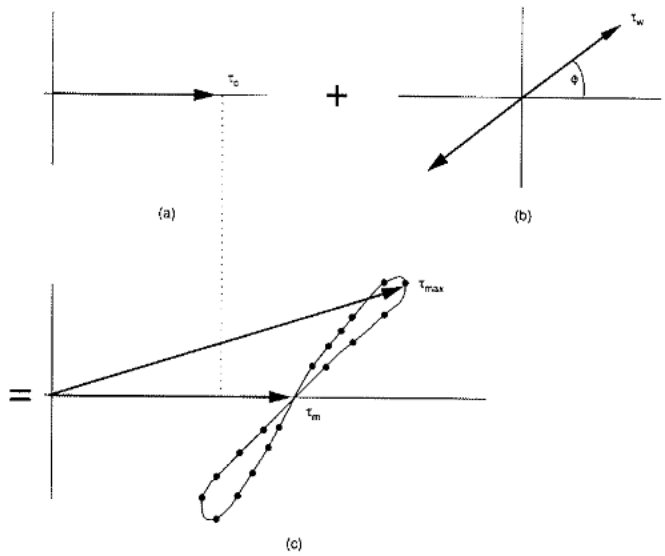
$\tau_{max} = [(\tau_m + \tau_w\cos\Phi)^2 + (\tau_w\sin\Phi)^2]^{1/2}$ **Equation 4**

where:

Φ = angle between tidal current direction and orbital wave direction

Figure 10A.4.1 demonstrates the non-linear nature of bed shear stress under the combined influence of currents and waves.

Figure 10A.4.1 - Schematic diagram of non-linear interaction of wave and current bed shear stresses (from Soulsby, 1997)



A.4.4 CRITICAL ENTRAINMENT STRESS (THRESHOLD BED SHEAR STRESS)

The equation used to determine the critical (or threshold) shear stress for entrainment of sediment is Equation 77 in Soulsby (1997). This is shown below.

$\Theta_{cr} = 0.30/(1 + 1.2D_*) + 0.055[1 - \exp(-0.020D_*)]$ **Equation 5**

where:

$D_* = [g(s - 1)/v^2]^{1/3}d_{50}$ **Equation 6**

g = acceleration due to gravity

$s = \rho_s/\rho$ = specific density of the sediment (i.e. ratio of densities of sediment and water)

v = kinematic viscosity of water

d_{50} = median sediment grain size

The critical entrainment stress was calculated across the domain using the spatially varying map of d_{50} (as was used to determine the bed shear stress due to currents only). The spatially varying plots of bed shear stress due to combined currents and waves (both the mean and maximum stress) were compared with the critical entrainment stress map, in order to determine the percentage of time the threshold for sediment entrainment was exceeded. The resulting percentage exceedance plots were then used to help assess the baseline sediment regime. Specifically, any modelled changes to these exceedance plots (due to the proposed wind farm developments) allow the magnitude of the effect of the developments on the sediment regime and coastal processes to be quantified and assessed.

A.4.5 REFERENCES

Soulsby, R. 1997. Dynamics of Marine Sands: A Manual for Practical Applications, Thomas Telford.