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OFFSHORE WINDFARMS – AN APPROACH TO SCOUR ASSESSMENT

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The development of offshore wind farms, potentially, requires the investigation of two principal scour issues, that related to the presence of a pipeline/cable and that due to the presence of the turbine structures. This paper presents a case study of an offshore wind farm from the west coast of the UK at Scarweather Sands in the Bristol Channel. A comparison is made between an empirical formula approach to scour prediction against field data. Only the current alone case has been considered due to the low wave activity over the period of the survey.

1 Introduction

1.1. *Scour Issues*

Placing a structure in the marine environment will lead to a change in the flow pattern in its immediate locality due to its presence. These changes will result in one or more of the following occurring:

- Flow contraction
- Horseshoe vortex formation in front of the structure
- Lee-wake vortices behind the structure (with or without vortex shedding)
- Reflection and diffraction of waves
- Wave breaking
- Turbulence generation
- Pressure differentials in the soil leading to liquefaction

With the occurrence of these phenomena there is usually an observed increase in the local sediment transport capacity and, therefore, and an increased tendency to scour. Therefore, an understanding of the scour potential is important in the context of offshore wind farms since it may lead to some or all of the following:

- Compromise of the structural stability of the turbines
- Increased sediment transport (both suspended and bedload), including transfer of sediment between coastal areas
- Development of freespans in cable route

Scour processes in the marine environment are more complex than those due to steady flow alone (e.g. rivers) due to the effect of waves and the combined effect of currents and waves. Herbich (1981) and Herbich *et al.* (1984) presented results from some of the first detailed investigations on the impact of scour on marine structures. Much of their work was based on empirical type design rules since knowledge of many of the hydrodynamic processes was still poorly understood. More recently, Whitehouse (1998) presented a review of the developments in scour into the 1990's, whilst Sumer and Fredsøe (2002) have provided a comprehensive account of scour at marine structures, incorporating state-of-the-art knowledge.

The development of offshore wind farms, potentially, requires the investigation of two principal scour issues, that related to the presence of a pipeline/cable and that due to the presence of the turbine structures, whether that is a single pile structure, gravity base or hybrid design (e.g. tripod structure). A Review and assessment of the potential effects on coastal processes related to the development of offshore windfarms around the UK coast has recently been completed for the UK Government (Cooper and Beiboer, 2002).

The following sections present a case study of an offshore wind farm from the west coast of the UK at Scarweather Sands in the Bristol Channel. A comparison is made between the empirical formulae available to undertake a first-order estimate of the scour potential due to the presence of a structure in the marine environment against field data. The scour is considered to be a function of the current alone, since wave activity on the day of the survey was minimal.

2 Foundation scour – Theory

2.1. *Wave Diffraction*

It is commonly accepted that diffraction effects around a cylinder become important when the ratio D/L becomes greater than 0.2 (Isaacson, 1979); where D is the diameter of the pile and L is the wavelength. For the Scarweather offshore wind farm the diameter of the proposed met. mast monopile structure is 2.2m, therefore,

$$\frac{D}{L} = \frac{2.2}{L} > 0.2 \qquad \therefore \qquad L < 11\text{m} \qquad (1)$$

The slender-pile regime will exist if the pile diameter, D, is small relative to the wavelength, L, and it is this regime that is assumed to exist for the present case based on the results of the wave modelling.

2.1. *Scour around a slender pile in currents:*

In steady currents, an important element in the scour process is the horseshoe vortex. In conjunction with the contraction of the streamlines at the edges of the pile, this vortex can erode a significant amount of sediment away from the vicinity of the pile and result in the formation of a truncated cone-shaped scour hole.

The flow pattern near a pile is quite complex and has been investigated by numerous researchers, for example, Breusers and Raudkivi (1991), Melville and Coleman (2000) and will not be described in any detail here. However, the principal features of scour round a circular pile are well defined: the downflow at the upstream face of the pile; the horseshoe vortex at the base of the pile; a surface roller (or bow wave) at the upstream face of the pile; and wake vortices downstream of the pile (Figure 1).

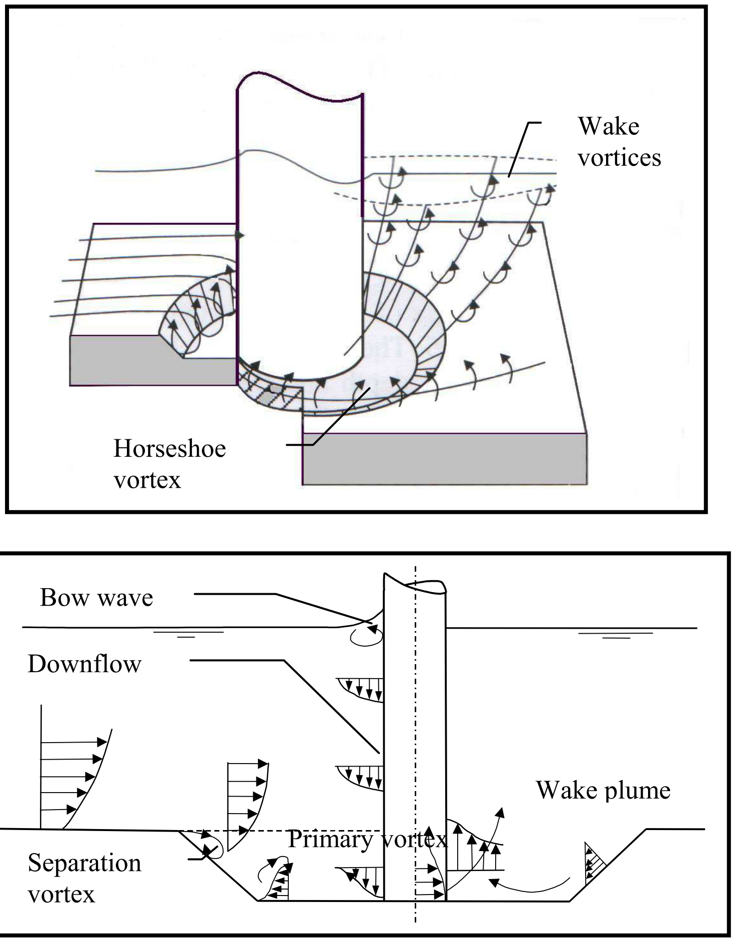


Figure 1. Flow pattern around a cylindrical pile (after Herbich *et al.* 1984).

Much literature is available for scour depth under steady flow. Breusers *et al.* (1977) presented a simple expression for scour depth under live-bed scour and this has been extended by Sumer *et al.* (1992) by assessing the statistics of the original data such that:

$$\frac{S_e}{D} = 1.3 + \sigma_{S/D} \qquad (2)$$

where $\sigma_{S/D}$ is the standard deviation of the scour depth, S_e, to pile diameter ratio. Based on experimental data $\sigma_{S/D}$ is taken to be 0.7.

Numerous equations have been proposed for the estimation of the depth of local scour at structures (Melville and Coleman, 2000). Examples of other formulas in use for estimating scour depth under steady currents are those of Johnson (1992) and Richardson and Davis (2001). The Richardson and Davis formulation (Eqn 3) is used in the US Department of Transport, Federal Highway Administration (FHWA) Hydraulic Engineering Circular (HEC) No.18 for determining scour at bridges.

$$S_e = 2.0K_1K_2K_3K_4h_0F_r^{0.43}\left(\frac{D}{h_0}\right)^{0.65} \quad (3)$$

Where D = the pile diameter (m); h_0 = flow depth (m); K_1 = correction factor for pile nose shape; K_2 = correction factor for angle of attack of flow; K_3 = correction factor for bed condition; K_4 = correction factor for size of bed material; F_r = Froude number.

2.1. *Effect of Tidal Flow*

All the above equations are for steady flow. Relatively little work has been undertaken to investigate scour due to tidal flow in comparison to studies undertaken for unidirectional flow. Since the flow reverses direction with the tide consequently the scour development will take place in two directions. The local scour depth can be estimated using the same equations as for unidirectional river flow, although scour development is typically reduced due to sediment eroded during the first phase of the tide being deposited on the reversing part of the tidal cycle. In addition to the astronomical variation of the tide, other factors that may affect local scour in tidal areas are meteorological effects such as storm surges and the relative magnitudes of the fluvial and tidal flows.

3. Scarweather OWF Case Study

United Utilities Green Energy Ltd. (UUGEL) pre-qualified for a 25 year-lease of a 10km^2 area of the seabed from the Crown Estate for the development of an offshore wind farm. The allocated site is in the lee of a sandbank known as Scarweather Sands, located towards the south-east of Swansea Bay in the Bristol Channel (Figure 2). The development site also extends across parts of the adjacent Hugo Bank. The Bristol channel is a macro tidal environment with some of the largest tidal ranges in the world.

A meteorological mast was installed at the Scarweather Sands offshore wind farm site in May 2003. The mast consisted of a 2.2m diameter mono-pile without scour protection. The position of the Met. mast coincided with the 6m depth contour.

Shortly after installation, monitoring was undertaken using multi-beam sonar to assess the bathymetry in the immediate vicinity of the mast. The survey area was 300m by 300m centred on the mast location. The survey was undertaken over a flood tide from around low water up to high water two days after the lowest neap tide in the particular spring-neap cycle (Figure 3). Tidal corrections for the survey depths were undertaken automatically with reference to Chart Datum at Port Talbot.

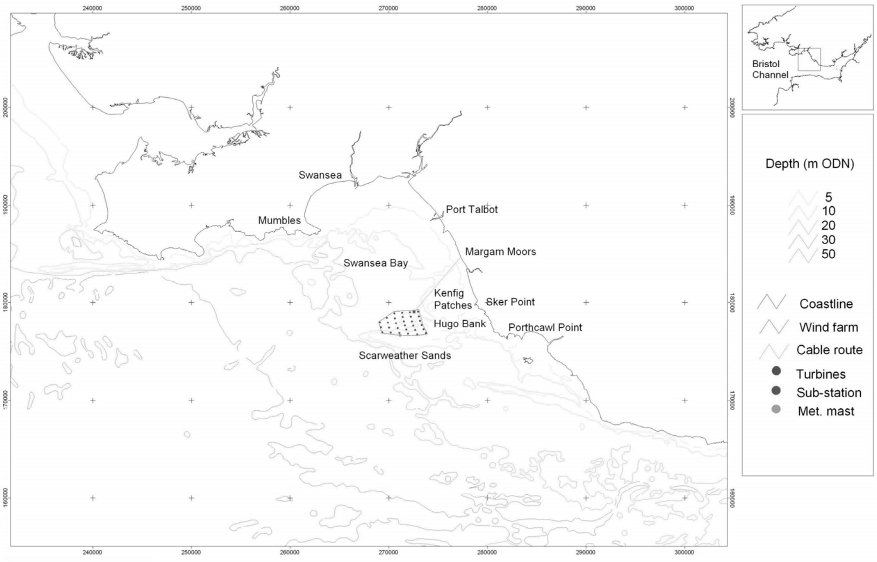


Figure 2. Location of Scarweather Offshore Wind Farm.

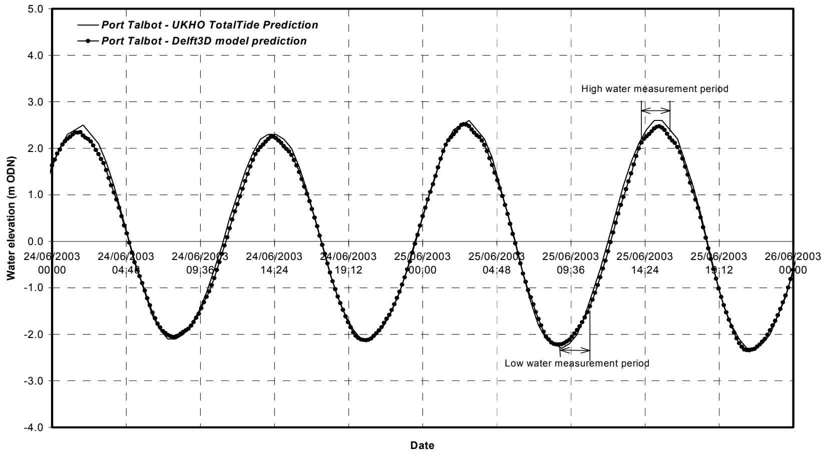
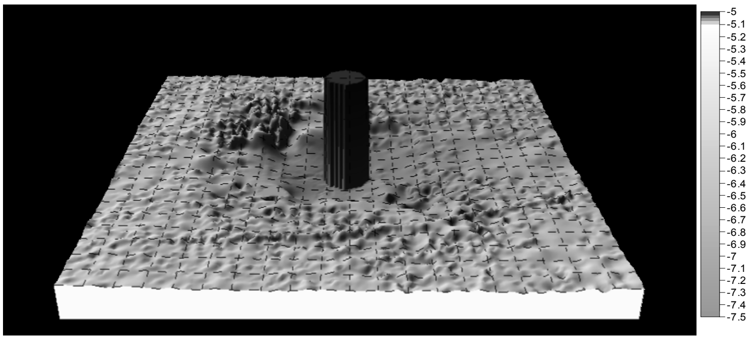


Figure 3. Predicted water level at Port Talbot.

4. Results and Discussion

The results from the multi-beam survey show that scour effects are limited to the immediate area around the mast. However, it is also evident that the seabed around the met. mast responds to changes in the flow even over a half tidal cycle (Figure 4).

Around Low Water:



Around High Water:

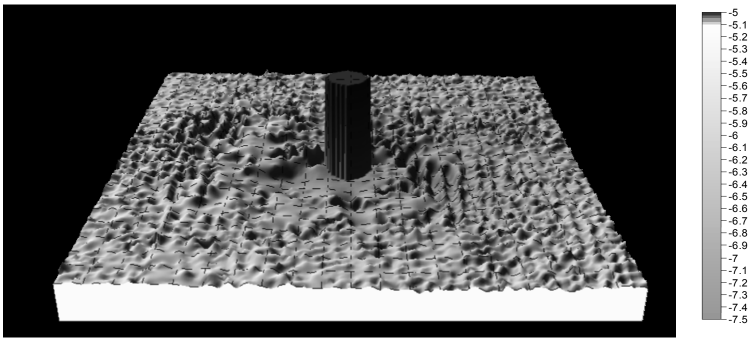


Figure 4. Surface plots showing evidence of scour around the met mast. Depths are in m relative to chart Datum (Port Talbot)

Also evident in Figure 4 are the tidal effects on scour development. From the ‘low water’ plot, which corresponds to an incoming flood tide, the scour hole is elongated along the path of the tide with a steeper profile on the upstream side of the mast (≈ 29°). This is close to the angle of internal friction (30°). The downstream slope is much less steep (≈ 14°). The scour hole corresponding to around high water shows a more symmetrical profile with a slightly elongated scour hole in the direction of the ebbing tide.

The average scour hole depths for the low water and high water measurement periods are 1.3m and 0.6m, respectively. Ignoring the effects of waves the equilibrium scour depth predicted from Eqn (2) is 3.6m assuming a standard deviation of 0.7. However, if we wish to make an assessment of the scour depth through a tidal cycle then it is necessary to adopt a different approach. Using the formula of Richardson and Davis (2001) it is possible to generate a time-varying depth of scour. To put the scour hole generation into some time frame the following empirical expressions have been applied (see Sumer and Fredsøe, 2002).

$$S(t) = S_e\left[1 - \exp\left(-\frac{t}{T_S}\right)\right] \quad (4)$$

$$T_* = \frac{\delta\theta^{-2.2}}{2000D} \quad (5)$$

Where S is the scour depth with time, δ is the boundary layer thickness (assumed to be the flow depth for tidal flow) and θ is the Shields parameter. To put these normalized expressions for time-scale back into a real time frame Sumer and Fredsøe use the following expression.

$$T_* = \frac{\left(g(s-1)d_{50}^3\right)^{1/2}}{D^2} T_S \quad (6)$$

Where d_{50} = median grain diameter; g = acceleration due to gravity; s = ratio of densities of grain and water. Figure 5 shows the predicted variation in scour depth with time.

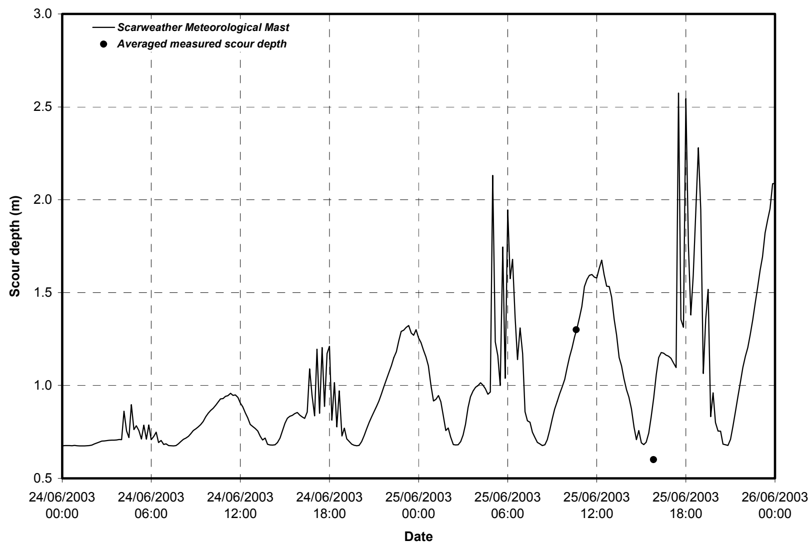


Figure 5. Predicted scour depth at the Meteorological Mast.

The predicted depths correspond well with those determined from the field measurements, although the predicted scour depth around low water is somewhat larger than that observed in the field (between 0.69m and 0.83m). Such an approach ignores the effect of waves and any underlying movement of the seabed. However, wave action was not significant during the period of the measurements. To obtain a better understanding of the behaviour of the seabed due to the combined influence of waves and tides around the mast, it would be useful to combine the area surveys with continual monitoring by 'instrumenting' the structure.

4. Conclusions

It has been demonstrated that it is possible to use an existing scour formula for steady flow and apply it to a tidal environment and obtain good predictions of scour depth over a half-tidal cycle by taking into account the time-varying component of the scour. However, such an approach may not be universally valid or have limited application depending on the prevailing hydrodynamic conditions. To investigate the longer-term effects of scour, particularly under combined waves and current it is suggested that such area bathymetric surveys should be combined with continual measurements.

Acknowledgments

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