Exercise 1:

Forces on slender bodies in currents/waves. Subsea pipeline stability analysis

Consider the pipeline sketched in Fig. 1 is laid on a sandy bed at a water depth of h = 19 m. The friction coefficient for the pipe and sand-bottom is μ = 0.7. Assume density of seawater equal 1025 kg/m^3 and kinematic viscosity equal $1 \cdot 10^{-6}$ m^2/s. Gravitational acceleration can be taken as 9.81 m/s^2.

The steel pipe is coated by a concrete cover. This is to achieve stability of the pipeline. The densities of steel, concrete and oil are given as ρ_{steel} = 7800 kg/m^3, $\rho_{concrete}$ = 3000 kg/m^3, ρ_{oil} = 800 kg/m^3.

The design current at the pipelines locality is due to the tidal event. The direction of this current is at right angle to the pipeline, and the current velocity U_c at the level of the pipe center is 2.5 m/s.

The design wave has the following properties: the wave period is T = 10.2 s, the wave height is H = 4.7 m. (These figures reflect extreme single wave induced oscillatory cycle in the design seastate.) The direction of this design wave is at an angle of 45° to the pipe (seen from above).

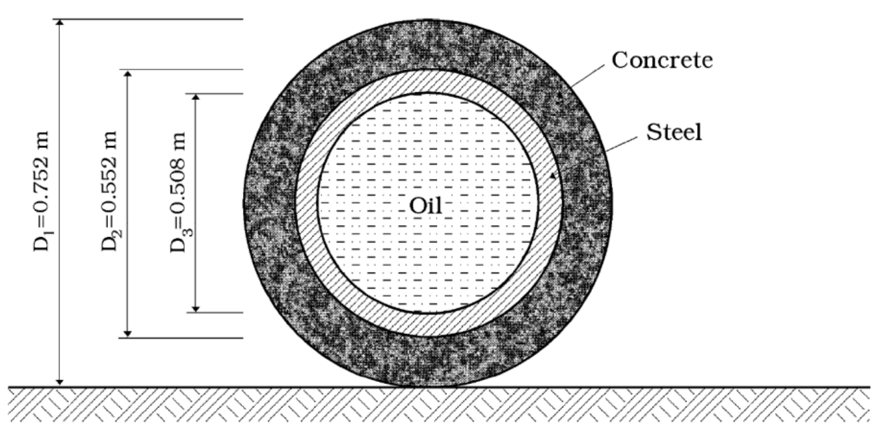

Figure 1: Subsea pipeline laid on a sandy bed, cross-sectional view.

Verify if the pipeline remains stable under these hydrodynamic loadings. In the calculations, assume a pipe (concrete coating) surface roughness of $k = 1 \cdot 10^{-3}$ m, and that the equivalent surface roughness, k_s (Sumer and Fredsøe, 2006, Example 1.1, p. 14) is equal to the roughness of the surface. If the pipeline is not stable, find the thickness of the concrete coating necessary for the stability of the pipeline.

There are two stability conditions: (a) the submerged weight of the pipe has to be greater than the lift force, and (b) the horizontal frictional force should exceed the in-line force, the combined drag and inertia forces. Hence,

1. Indicate the different forces on Figure 1.
2. Calculate the submerged weight, W_s (N/m), of the pipeline per unit length.
3. Write down expressions/equations for the stability conditions using only W_s, F_L, F_H and μ. Here, F_L is the lift force, F_H is the in-line force, and μ is the friction coefficient.

and repeat each of the following action items for the three cases: current alone; wave alone; and combined wave and current

4. Write down equations for the lift and in-line force (Morison equation, Sumer and Fredsøe 2006, Eq. 4.29). Note, the Morison equation reduces to the drag force for a steady current (Sumer and Fredsøe 2006, Eq. 2.8).
5. Determine Reynolds number and Keulegan-Carpenter number (waves only as $KC = \infty$ for a current).
6. Determine appropriate force coefficients from diagrams in sections 2.7 and 4.7 of the lecture book (Sumer and Fredsøe 2006). List the force coefficients in a table (Table 1).
   a. Current alone and waves alone: Note, section 2.7 and 4.7 may refer you to other parts of the textbook.
   b. Combined wave and current: Apply the information in Sumer and Fredsøe 2006, Figs. 4.23 and 4.24 to establish force

coefficients in the case of combined wave and current. List also these coefficients in Table 1.

7. Verify if the pipeline remains stable in current alone, waves alone and combined waves and current.

8. If the pipeline is not stable, find the thickness of the concrete coating necessary for the stability of the pipeline.

Discuss all of your results in detail.

The following item is optional and not part of the evaluation

Marine growth builds up over time and should be accounted for when calculating forces on marine pipelines, see DS 449 and section 6.7.4 in DNV RP-C205. Note, DS/EN ISO 19902 has replaced DS 449 and DNVs recommended practices are being replaced by DNVGL recommended practices.

9. Verify if the pipeline remains stable when marine growth is accounted for.

References:

DNV RP-C205 “Environmental conditions and environmental loads”.

DNV RP-F109 “On-bottom stability design of submarine pipelines”.

Sumer, B. M. and Fredsøe, J. (2006). Hydrodynamics around cylindrical structures. World Scientific.

Carstensen, S. (2016). Addendum to the textbook: Sumer and Fredsøe (2006) “Hydrodynamics around cylindrical structures.”

DS 449 (1984) “Pile supported offshore steel structures”

DS/EN ISO 19902 (2020) “Petroleum and natural gas industries – Fixed steel offshore structures”