6 On - Bottom Stability

On-bottom stability is one of the most critical elements in the design of submarine pipelines. Empirical research into vertical and horizontal stability during installation and operation of both buried and unburied structures began with ancient harbor structures. This entered into a new phases with the mid-19th Century transatlantic cable crossings and ocean outfalls of the 1890s. While sanitary and environmental engineers have looked at the behavior of effluents in the sea, the increasing development of offshore petroleum production since about 1950 has sparked most of the theoretical and empirical studies of on-bottom stability that are identified in this chapter and that constitute the operational extensions to Terzaghi's classic work (24).

Pipelines are generally empty during installation and filled with water during operation. The pipeline weight in both conditions must be calculated and then used in various stability calculations. Most outfall pipelines are buried near the shoreline and unburied at the discharge end. In this case both buried and unburied stability must be calculated.

Recent construction of outfall tunnels provide for either the outfall terminus or a series of risers to diffusers that extend above the sea floor. Here, the weight of the tunnel boring machine can be an additional design factor.

6.1 Forces

The external forces of importance to on-bottom stability include soil forces and hydrodynamic forces.

6.1.1 Soil Forces

Soil forces depend upon soil type. Generally, the vertical soil forces are known as bearing capacity. Horizontal forces are the sum of frictional forces and passive soil resistance (3,5,21,25). Here, the possibility for liquefaction requires special attention.

For horizontal stability, the frictional force is a function of the effective vertical loading. Passive soil resistance is a function of the embedment of the pipeline into the soil. For rocky Seabees, hard clay, and dense sand the frictional forces are dominant with little or no contribution from the passive soil resistance that dominates in soft clay and loose sand. In conventional pipeline design, only
frictional soil forces were considered, occasionally with higher friction coefficients that were considered to account for some pipeline embedment into the seabed. Investigations carried out during the 1980s provide better descriptions of the two parts of soil resistance for sand and clay (5,21).

### 6.1.2 Hydrodynamic Forces

Traditional pipeline design considered only steady current flow and corresponding force coefficients (22). Recent investigations have clearly demonstrated that the loading caused by waves, sometimes combined with that from steady flow, is substantially larger (6,7,13,23). In steady flow, water passing over a pipeline creates a decrease in pressure both on the upper and downstream sides of the pipeline. This pressure field is integrated from two force components, the horizontal drag force, $F_D$, and the vertical lift force, $F_L$, where

\[
F_D = \frac{1}{2} \rho \ D \ C_D \ U^2 \quad (6.1)
\]

and

\[
F_L = \frac{1}{2} \rho \ D \ C_L \ U^2 \quad (6.2)
\]

where $C_D$ and $C_L$ are experimentally defined coefficients.

Wave current velocities vary over time and are reflected in water particle accelerations (see Table 2.2) that create a pressure field around the pipeline. The integration of this pressure field yields a force in the horizontal direction, the inertial force:

\[
F_I = \frac{\pi}{4} \rho \ D^2 \ C_M \cdot a \quad (6.3)
\]

where $a$ is the water particle acceleration at the seabed, and $C_M$ is the inertia coefficient. The total horizontal hydrodynamic force is then described as

\[
F_H = F_D + F_I = \frac{1}{2} \rho \ D \ C_D \ U(t) \ |(U(t)| + \frac{\pi}{4} \rho \ D^2 \ C_M \cdot a(t) \quad (6.4)
\]

whereas the lift force remains:

\[
F_L = \frac{1}{2} \rho \ D \ C_L \ U^2(t) \quad (6.5)
\]

Recent literature provides more refined force descriptions (20, 23).

The vector sum of the hydrodynamic driving forces and the soil resistance forces determines the stability of the pipeline. Special consideration on loading needs to be given in the case of suspended pipeline sections. The vortex shedding and associated dynamic loading can cause severe vibrations and associated fatigue (see Chapter 7).