Chapter 1

Introduction and basic concepts

1.1 Introduction

When a structure is placed in a marine environment, the presence of the structure will change the flow pattern in its immediate neighbourhood, resulting in one or more of the following phenomena:

1. the contraction of flow;
2. the formation of a horseshoe vortex in front of the structure;
3. the formation of lee-wake vortices (with or without vortex shedding) behind the structure;
4. the generation of turbulence;
5. the occurrence of reflection and diffraction of waves;
6. the occurrence of wave breaking; and
7. the pressure differentials in the soil that may produce "quick" condition/liquefaction allowing material to be carried off by currents.

These changes usually cause an increase in the local sediment transport capacity and thus lead to scour.

(The term "scour" is used instead of the more general term "erosion" to distinguish the process caused by the presence of a structure, Coastal Engineering Manual, 2001).

The scour is a threat to the stability of the structure.

The type of structure where such local scour is involved can vary considerably: it may be a simple structure such as a plain pipeline or a pile or the trunk section of a vertical-wall breakwater, or it may be a complex structure such as a group of piles, a subsea template, a protection structure with horizontal and vertical members, or an offshore platform.

Such structures are usually exposed to currents, waves, and combined waves and currents. Clearly, scour processes in the marine environment (with waves being the dominating flow effect) are more complex than in steady-current flows such as in rivers. In river hydraulics, a long tradition exists for studying scour around hydraulic structures. Scour at a bridge pier, for example, has been studied most extensively (Breusers and Raudkivi, 1991; Melville and Coleman, 2000), simply because it has been realized that this is an important cause of bridge failure. The scour problems in coastal and offshore engineering have not received the same kind of attention. One of the first important contributions is that of Herbich, who published two early monographs on the subject, Herbich (1981) and Herbich et al. (1984). However, at the time of publication of these monographs, the knowledge of the hydrodynamic processes was quite sparse, and many of the design rules were based on only empirical information. Recent years, however, have witnessed a rapid development of the knowledge of flow and scour processes around marine structures, particularly those which have simple geometries such as pipelines, piles, etc. A substantial volume of knowledge has accumulated as a result of this intensive research activity. The book by Whitehouse (1998) has covered developments which took place until mid nineties.

The present book is an attempt to give a comprehensive account of scour at marine structures, and also taking into consideration all state-of-the-art knowledge. It is our aim to describe the *hydrodynamic processes causing scour* in details. With a hydrodynamic understanding, it is easier for the consulting engineer to predict expected scour in those many cases, where physical model tests are not available.

We shall start off with the basic concepts (the present chapter). These include the amplification factor in the bed shear stress in the vicinity of a structure; the equilibrium scour depth and the time scale of scour; the clear-water scour versus the live-bed scour; and the local scour versus the global scour.

Next, we shall concentrate on scour at pipelines (Chapter 2), which will be followed by a full account of scour around piles (Chapters 3-6); namely, scour around slender piles (Chapter 3), scour around a group of slender piles (Chapter 4), scour at "complex" structures comprising vertical/inclined and horizontal slender cylindrical elements (such as a piled steel platform, a subsea template, or a wind turbine foundation) (Chapter 5), and scour around large piles (Chapter 6). In Chapters 7 and 8, attention will be concentrated on scour at breakwaters and seawalls, respectively. Chapter 9 will study ship-propeller scour. Chapter 10 will address the question of the impact of liquefaction.

It may be noted that some marine-engineering projects may include structural elements or flow conditions that are typically associated with inland waters and estuaries. Breusers and Raudkivi (1991), Hoffmans and Verheij (1997) and Melville and Coleman (2000) review techniques for estimating maximum scour characteristics for cases that may be applicable to marine-engineering projects, such as scour downstream of sills and stone blankets; scour downstream of hard bottoms due to horizontal submerged jets; scour at control structures due to plunging jets; scour at 2-D and 3-D culverts; and scour at abutments and spur dikes.

The topics covered in these latter books and the material presented in the present book form a complementary source of information on scour.

1.2 Amplification factor

Consider a structure placed in a marine environment. The presence of the structure will cause the flow in its neighborhood to change. This local change in the flow will generally cause an increase in the bed shear stress and in the turbulence level. The sediment transport close to the structure is increased mainly because:

1. the average bed shear stress is increased close to the structure, and
2. the degree of turbulence is increased in the vicinity of the structure.

Both features will lead to an increase in the local sediment transport capacity. Today, however, much more knowledge is available about item (1) than about item (2).

Usually the increase in the bed shear stress is expressed in terms of the so-called **amplification factor** defined by

$$\alpha = \frac{\tau}{\tau_\infty} \tag{1.1}$$

in which τ = the bed shear stress and τ_∞ = the bed shear stress for the undisturbed flow. This is illustrated in Fig. 3.10 in Chapter 3 for a pile exposed to a steady current. (Only one half plane is shown in the figure for reasons of symmetry). As seen, the amplification factor can be very large near the structure (as large as $O(10)$).

Owing to the local increase in α (i.e., $\alpha > 1$), the sediment transport capacity will increase (since the rate of sediment transport as bed load $q_b \sim \tau^{3/2}$), and presumably the bed will be eroded, the *scour process.* Fig. 3.20 in Chapter 3 shows an illustration of the scour hole generated in the vicinity of a pile subjected to a steady current.

This process will continue until the scour reaches such levels that the bed shear stress around the structure becomes $\alpha = O(1)$. The stage where the scour process comes to an end is called the equilibrium stage. (It should be noted that, in the preceding discussion, the formula $q_b \sim \tau^{3/2}$ is assumed to be valid in the present context also, although it is anticipated that the presence of the "structure-generated turbulence" may further increase the sediment transport capacity, as discussed in the preceding paragraphs).

1.3 Equilibrium scour depth and time scale of scour

From the preceding considerations, the scour develops towards the equilibrium stage through a transitional period, as illustrated schematically in Fig. 1.1. The scour depth corresponding to the equilibrium stage, S in Fig. 1.1, is called the **equilibrium scour depth**.

It is also seen from Fig. 1.1 that, for a substantial amount of scour to develop, a certain amount of time must elapse. This time is called the **time scale** of the scour process. The time scale of the scour process may be defined in several ways. The following definition will be adopted in the present treatment:

$$S_t = S\left(1 - \exp(-\frac{t}{T})\right) \qquad (1.2)$$

in which T = the time scale of the scour process, and corresponds to the time period T indicated in Fig. 1.1 where the dashed line is tangent to the scour-depth-versus-time curve at $t = 0$.

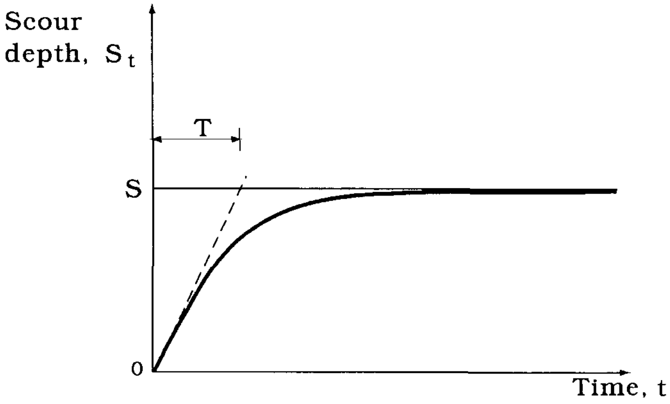

Figure 1.1: Time development of scour depth.

The aforementioned quantities, namely the equilibrium scour depth and the time scale, are two major parameters in scour studies.

The scour depth is important because, given the structure and the flow climate, it indicates the degree of scour potential. The assessment of scour depth is essential in the design of both (1) the foundation of the structure and (2) the scour protection work.

The time scale is also equally important. A scour hole produced after a storm may be backfilled. Normally, the question asked in practice is whether any substantial amount of scour would occur over the backfilled area during the next storm. Obviously, for a substantial amount of scour to occur, the storm should prevail over a space of time larger than the time scale of the scour process. Clearly, to answer the aforementioned question, the time scale of scour must be known.

1.4 Clear-water scour and live-bed scour

Scour may be classified in two categories: the clear-water scour and the live-bed scour.

In the case of the **clear-water scour**, no sediment motion takes place *far* from the structure ($\theta < \theta_{cr}$), while, in the case of the **live-bed scour**, the sediment transport prevails over the entire bed ($\theta > \theta_{cr}$). Here θ is the

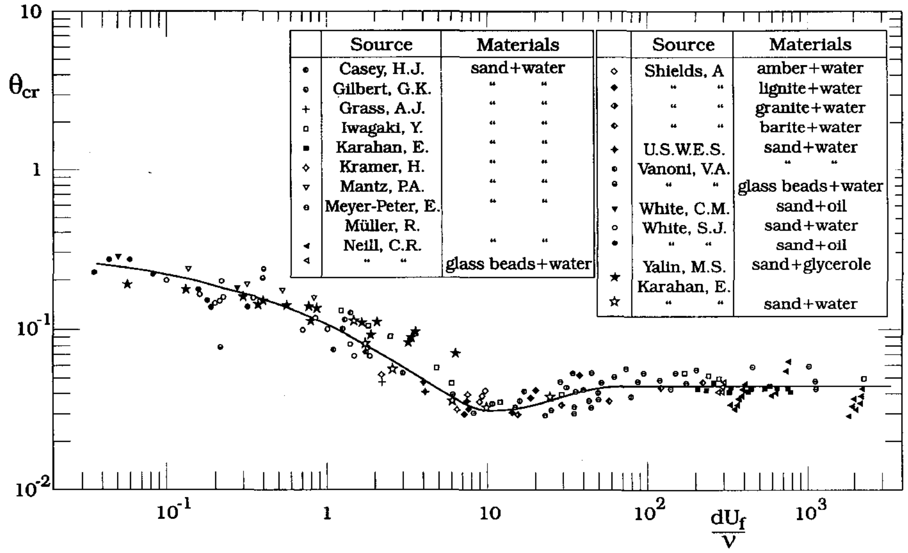

Figure 1.2: Initiation of motion at the bed. Data compiled by Yalin and Karahan (1979).

undisturbed Shields parameter defined by

$$\theta = \frac{U_f^2}{g(s-1)d} \tag{1.3}$$

in which $U_f = \sqrt{\tau_\infty/\rho}$, the undisturbed bed shear velocity (in the case of waves, τ_∞ should be replaced by $\tau_{\max,\infty}$, the maximum value of the undisturbed bed shear stress), g = the acceleration due to gravity, s = the specific gravity of sediment grains and d = the grain size. θ_{cr} is the critical value of the Shields parameter corresponding to the initiation of sediment motion at the bed. θ_{cr} is a function of the grain Reynolds number, dU_f/ν, Fig. 1.2. (For basic concepts regarding the sediment transport, Chapter 7 in the book by Fredsøe and Deigaard (1992) may be consulted).

In the clear water case, the variation of the scour depth with θ is more pronounced (as illustrated in Fig. 1.3 for the case of scour below a pipeline): the scour depth increases from zero at very small values of θ up to θ_{cr} ($\simeq$ 0.05

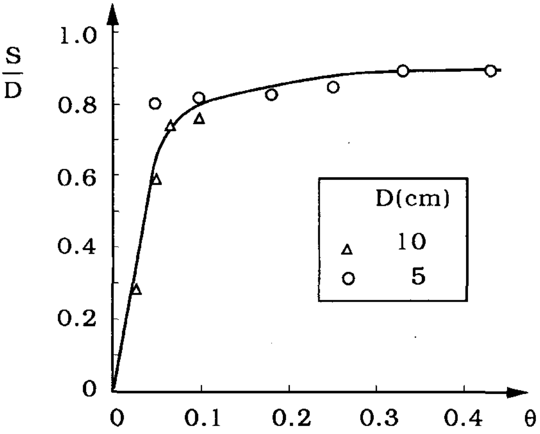

Figure 1.3: Variation of equilibrium scour depth (for a pipeline) versus the Shields parameter. The initial clearance from the bed is nil. Mao (1986).

for the experiments presented in Fig. 1.3, c.f. Fig. 1.2). At very low θ values, no scour will occur because, in this case, even the amplified local bed shear stress may still be too small to cause sediment transport. However, when the live-bed case is reached, and beyond ($\theta > \theta_{cr}$), a very small variation of the scour depth with θ is observed (see also, for example, Hjorth, 1975, for the current alone case, and Sumer and Fredsøe, 1990, for the waves alone case). This is because any change in θ results in corresponding changes in sediment transport, and these changes occur both inside and outside of the scour hole in equivalent amounts, eventually causing only small changes in the equilibrium scour hole.

1.5 Local and global scour

The local scour and the global scour will be described by reference to two examples: Scour at a piled steel platform and scour at a bridge pier.

Consider a piled steel platform comprising horizontal and vertical members (Fig. 1.4). When this structure is exposed to flow action, two kinds of scour will take place; the local scour around the individual structural elements such as that around the supporting piles, and the global scour beneath

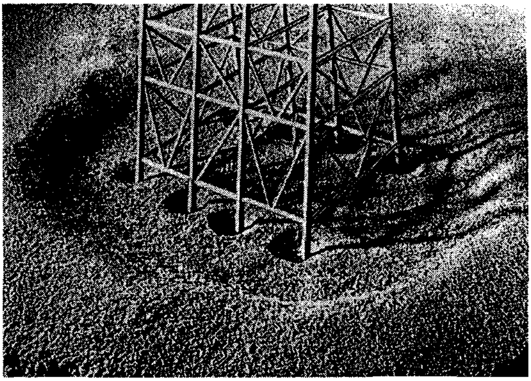

Figure 1.4: Scour around a piled steel platform. A conceptual picture. Angus and Moore (1982). By courtesy of the Offshore Technology Conference.

and around the structure in the form of a saucer-shaped depression, as illustrated in the conceptual picture in Fig. 1.4. The global scour here is due to the combined action of all the flow effects generated by the individual structural elements, namely the contraction of flow and the "turbulence" generated by the structural elements.

Likewise, scour at a bridge occurs as local scour and global scour (Fig. 1.5). Local scour occurs around the individual piers and at the abutments, while the global scour occurs as the general lowering of the river bed, as sketched in Fig. 1.5. The global scour in this example may, in addition to the contraction scour, occur due to hydrometeorological changes (e.g., prolonged high flows), geomorphological changes (e.g., lowering of channel base level due to catchment wide adjustment in geomorphology), human activities (e.g., dam construction), bank erosion (caused by channel widening, meander migration, a change in the river controls, or a sudden change in the river course, e.g., with the formation of a meander-loop cut-off) (Melville and Coleman, 2000).

1.6 References

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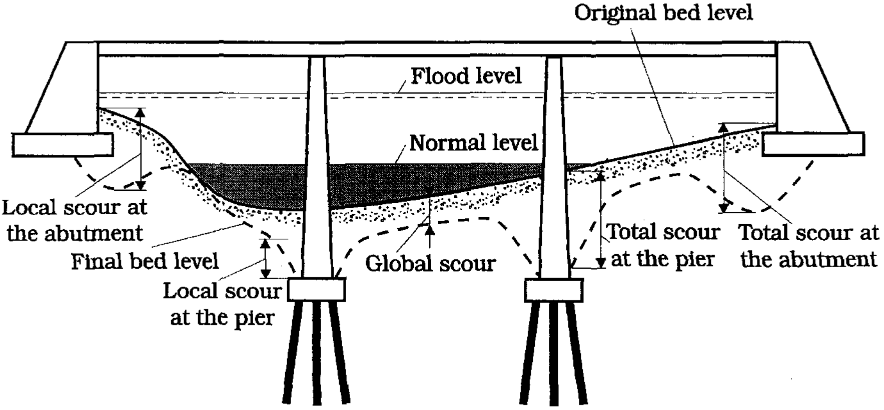

Figure 1.5: The types of scour that can occur at a bridge. Adapted from Melville and Coleman (2000).

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